Using ergonomic risk assessment methods for designing inclusive work practices – a case study

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Using ergonomic risk assessment methods for designing inclusive work practices – a case study

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ABSTRACT:

In common with many industries, manufacturing faces the challenge of effective management of a diverse workforce. Humans differ greatly but traditional manufacturing work practices do not take into account human variability issues during the work design process. Variations in individual and organizational work performance due to many individual factors such as age, gender, level of skill, experience and background bring performance inconsistencies. This research investigates the effects of individual skill on work performance in general, and workplace safety and human well-being in particular. A research framework is proposed for highlighting major differences in work performing strategies, their potential impact on work performance and how these findings can be used for designing more inclusive work practices. A case study has been presented where ergonomics risk assessment methods have been used to validate the usefulness of this framework. It is also concluded that skill has a strong relationship with the level of risk attached to various task performing strategies.

Keywords: Ergonomic risk assessment; individual factors and human variability; inclusive design

1. Introduction

1.1 The diversity problem

Human differences influence human behaviour and can result in variations in working behaviours, strategies and methods that affect overall system productivity. There are many factors including age, level of skill, gender, experience, background and lifestyle that might influence work performance positively or negatively. A ‘design for all’, ‘inclusive design’ or ‘universal design’ approach attempts to accommodate the needs of the largest percentage of the population whilst accounting for this diversity. The challenge for design inclusivity is that it is difficult to design products, processes or environments that fit everyone every time. Therefore, inclusive design is about the appropriateness of any design for the individual (Vanderheiden, 2009).

This research arose from earlier work concerned with Activities of Daily Living which was part of the Extending QUAlity Life programme (Case et al., 2001, Porter et al., 2004). The focus was on the domestic environment. Subsequent work extended the scope to transport issues as part of the AUNT-SUE (Accessibility and User Needs in Transport –Sustainable User Environments) (Summerskill et al., 2010, Marshall et al., 2010). More recently the ageing population has become an important concern in the industrial environment. Legislation in the UK has removed compulsory retirement and so there is likely to be increasing numbers of older workers with reduced capability in some aspects.

1.2 Research aims and objectives

The overall aim of the research was to:

contribute to the understanding human variability issues and their relationships with workplace safety

The specific objectives were to:

investigate the relationship between skill and the risk of work-related musculoskeletal disorders (WMSDs);

propose a framework for designing inclusive work practices by using traditional risk assessment methods that might be used to quantify the effect of human variability in terms of workplace safety;

compare the OWAS (Ovako Working Posture Analysing System) and REBA (Rapid Entire Body Assessment) postural assessment methods.

1.3 Theory/Background

1.3.1 Diversity factors

The National Research Council and Institute of Medicine (NRC/IOM) have defined factors thought to affect individual or personal responses to workplace exposure, in terms of physiological and psychological attributes (NRC/IOM, 2001). Cole and Rivilis (2004) listed nine factors (demographics, age, work, anthropometry, psychological, life style, comorbidity, past history and social factors) and their potential underlying constructs (Table 1). The factors are considered to affect individuals in different ways. For example, social factors such as economic condition (poverty), minority and race, and divorced-widowed status can cause a low level of support and discrimination.

Table 1: What do individual factors represent? (Cole and Rivilis, 2004)

Usual naming of factor types	**Individual factor(s)**	**Potential construct(s)**
Demographic	Gender, Different tasks, capacities and reactions to stress, all resulting in	Differential labour market

Usual naming of factor types	Individual factor(s)	Potential construct(s)
	different exposures	
Age	Cumulative exposure	Decreased tolerance, Different skills and experience
Work	Work-style	Different biomechanical exposures
Anthropometry	Height and weight	Mismatch between equipment and person, Differential tissue demands
Psychological	Personality	Differential kinematics Differential coping capacity
Lifestyle	Physical activity, hobbies, sports Smoking, drugs	Additional loads or physical exposures, Additional exposures
Comorbidity	Diabetes, pregnancy Distress, depression	Additional internal exposures Altered biochemistry, different pain perception threshold
Past history	Episode of MSK disorder	Lower tolerance
Social	Divorced–widowed, Minority race, Poverty	Lower social support, Discrimination, Complex socio-health contexts

1.3.2 Work related musculoskeletal disorders

Work related musculoskeletal disorders (WMSDs) are costly in terms of lost wages, compensation costs and lost productivity. Estimates vary widely but one study attributed costs of $299 to $335 billion annually in the US in lost productivity to pain much of which arose from WMSDs (Gaskin and Richard, 2012). Similarly, the Health and Safety Executive (H.S.E., 2011) and the Bureau of Labor Statistics (B.L.S., 2010) have reported that a considerable proportion of workers had accidents at work and faced major types of injuries like handling injuries, slips and trips that ultimately result in lost working days. It is very important to consider the prevention of WMSDs and to highlight major risk factors causing these disorders. The risk factors are multifactorial; however, these can be classified into three main categories: individual, physical and psychosocial/organizational (Kee and Karwowski, 2007).

Because of the multifactorial nature of WMSDs, there has been much discussion on correlation to determine relationships between indices and prevalence of WMSDs with individual factors like age, gender, anthropometry, work strategy, hobbies, physical activities, and outside work. It has been concluded that individual factors influence a person's response to different risk factors in the workplace and elsewhere. However, these factors and their underlying constructs may contribute to prevalence of WMSDs in a variety of ways (Kerr, 2000, Cole and Rivilis, 2004, Wahlström, 2005).

Several studies have concluded that women are more likely to be exposed to WMSDs as they are more exposed to physical and psychosocial risk conditions at work (Punnett and Herbert, 2000, Treaster and Burr, 2004, Wahlström, 2005, Karlqvist et al., 2002, Aittomäki et al., 2005). However, some studies (Hooftman et al., 2009) found no gender differences.

Age is a contributing factor to WMSDs. Older workers prefer jobs with low workload as old age is associated with medical conditions and reduced physical functioning related to WMSDs (Landau et al., 2008, Welch at al., 2008). Older workers suffer from more serious but less frequent workplace injuries than younger workers and these can be reduced by understanding the consequences of reduced physical and cognitive abilities, as between the ages of 51 and 62 the prevalence of WMSDs may increase by up to 15% (Ilmarinen, 2002). Moreover, age-friendly workplaces may lead to higher productivity, competitiveness and sustainable business practices (Welch at al., 2008, Silverstein, 2008). A higher proportion of workers over the age of 55 lost work time because of their injuries, and workers over the age of 45 had a higher average number of lost work days per injury. However, there is some evidence of there being no significant relationship between age and WMSDs (Peek-Asa et al. 2004, Pransky et al. 2005).

Differences in working techniques also play an important role in exposing workers to risk factors. Keyserling et al. (2010) concluded that different workers perform their work in significantly different ways, and significant differences in lower body postures were observed (at 57 out of 79 engine assembly workstations). Similarly, gender also has effects on the selection of working techniques.

Dahlberg et al. (2004) observed that women more frequently use their hands above shoulder level, which is considered a risk factor for neck and shoulder disorders.

The differing physical demands of work are considered as major reasons for WMSDs. Quantitative biomechanical factors include awkward working postures, vibration, and high peak and static loads while qualitative work characteristics such as manual material handling and complex body movements also lead to a greater chance of WMSDs. The consequences for organizations are in terms of lower quality, reduced productivity, increases in the cost of wage compensation and medical expenses (Latzaa et al., 2000, Sobeih et al., 2006, Simon et al., 2008, Engels et al., 1996, Karwowsaki and Marras, 2003, Chaffin et al., 2006, Wassell et al., 2000, Pinzkea and Kopp, 2001, Keyserling et al., 1988, Ryan, 1989, Aarås et al., 1988, B.L.S., 2007).

In recent years, researchers have paid more attention to psychosocial factors at work and found that factors like high job stress, dissatisfaction, lack of job control, high job demands, high mental pressure and inadequate work support, and perception of an inadequate safety climate contribute significantly towards musculoskeletal complaints (Smith et al., 2004, Sobeih et al., 2006, Hofmann and Mark, 2006, Hollman et al., 2001, Stone et al., 2007, Simon et al., 2008, Lacey et al., 2007).

In the light of the above discussion, it can be concluded that as humans are different in their physical, psychological and cognitive abilities, so they respond differently to physical, psychosocial and organizational factors regarding risk exposure at work. As the global workforce is becoming more diversified, it is expected that these human variability issues will become more prominent. There is a need to explore relationships between individual factors and their potential impact on working strategies and risk exposure, so that these variability issues might be addressed during workplace design. This article highlights the skill variability issue, differences in working strategies and their impact on the risk of WMSDs by using ergonomics risk assessment methods.

1.3.3 Postural assessment methods

There are several established postural evaluation methods, including OWAS (Ovako Working Posture Analysing System) (Karhu et al., 1977, Karhu et al., 1981, and Karwowski, 2003) and REBA (Rapid

Entire Body Assessment) (Hignett and McAtamney, 2000, Janowitz et al., 2006). These methods are used to identify and highlight the sensitivity and level of musculoskeletal disorders (MSDs) associated with any adopted posture by generating posture codes for the back, arms, legs, neck and load being carried.

1.3.3.1 OWAS method

The OWAS method (Karhu et al., 1977, Karhu et al., 1981, and Karwowski, 2003) describes a working posture in relation to the posture of the back, arms and legs and the load. Postures of the back are classified into four categories, arms into three, legs into seven and three for the force applied (table 2).

Table 2: OWAS postures code definition (Karhu et al., 1977; Karhu et al., 1981; Karwowski and Marras, 2003)

Body parts	**OWAS code**	**Description of position**
Back	1	Back straight
	2	Back bent
	3	Back twisted
	4	Back bent and twisted
Arm	1	Both arms below shoulder level
	2	One arm at or above shoulder level
	3	Both arms at or above shoulder level
Leg	1	Sitting
	2	Standing on both straight legs
	3	Standing on one straight leg
	4	Standing or squatting on both feet, knees bent
	5	Standing or squatting on one foot, knee bent
	6	Kneeling on one or both knees
	7	Walking or moving
Load handle	1	Load < 10kg
	2	10 < Load < 20kg
	3	Load > 20kg

In this way, 252 (4 x 3 x 7 x 3) posture and load combinations are presented in the form of four digit codes. These codes define the level of risk attached with any adopted postures where the level of action category is determined using table 3.

Table 3: OWAS action codes from posture code combinations

Back	Arms	1			2			3			4			5			6			7			Legs
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Load
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

Posture combinations with higher risk of musculoskeletal disorders belong to higher action categories (Table 4).

Table 4: The OWAS action categories (Karhu et al., 1977, Karhu et al., 1981, and Karwowski, 2003)

Action Category	**Explanation**
1	Normal and natural posture with no harmful effect on the musculoskeletal system - No action required
2	Posture with some harmful effect on the musculoskeletal system – Corrective actions required in the near future
3	Postures have a harmful effect on the musculoskeletal system – Corrective actions should be done as soon as possible
4	The load caused by these postures has a very harmful effect on the musculoskeletal system – Corrective actions for improvement required immediately

The usefulness of OWAS has been validated in several occupational settings, including construction, automotive, agriculture, nursing and the poultry industries. The method is able to detect the level of discomfort and risk involved and to make suitable recommendations for the improvement of working strategy and workplace design to minimize or prevent work related musculoskeletal disorders (Karhu et al., 1977, Mattila et al., 1993, Engels et al., 1996, Scott and Lambe, 1996, Karwowski, 2003, Nevala, 1995).

1.3.3.2 REBA method

Like OWAS, the REBA method (Hignett and McAtamney, 2000, Janowitz et al., 2006) is a postural assessment method to assess the severity of musculoskeletal risk involved in working postures. Postural classification is based on the upper arms, lower arms, wrist, trunk, neck and legs and the loads, muscular activity caused by static and dynamic, rapidly changing or unstable postures and coupling effects. Five levels of action are recommended (Table 5). Action level 4 with very high level of risk demands immediate action, whereas action level 0 has negligible risk. The usefulness of the REBA method has been reported in the literature (Hignett, 2000, Janowitz et al., 2006).

Table 5: REBA action levels

Action level	**REBA score**	**Risk level**	**Action (including further assessment)**
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very high	Necessary now

From the above discussion, it can be said that observational techniques are useful in assessing postural loads for a wide range of occupational settings.

2. Method

The research method proposed is a framework (six step approach) (figure 1).

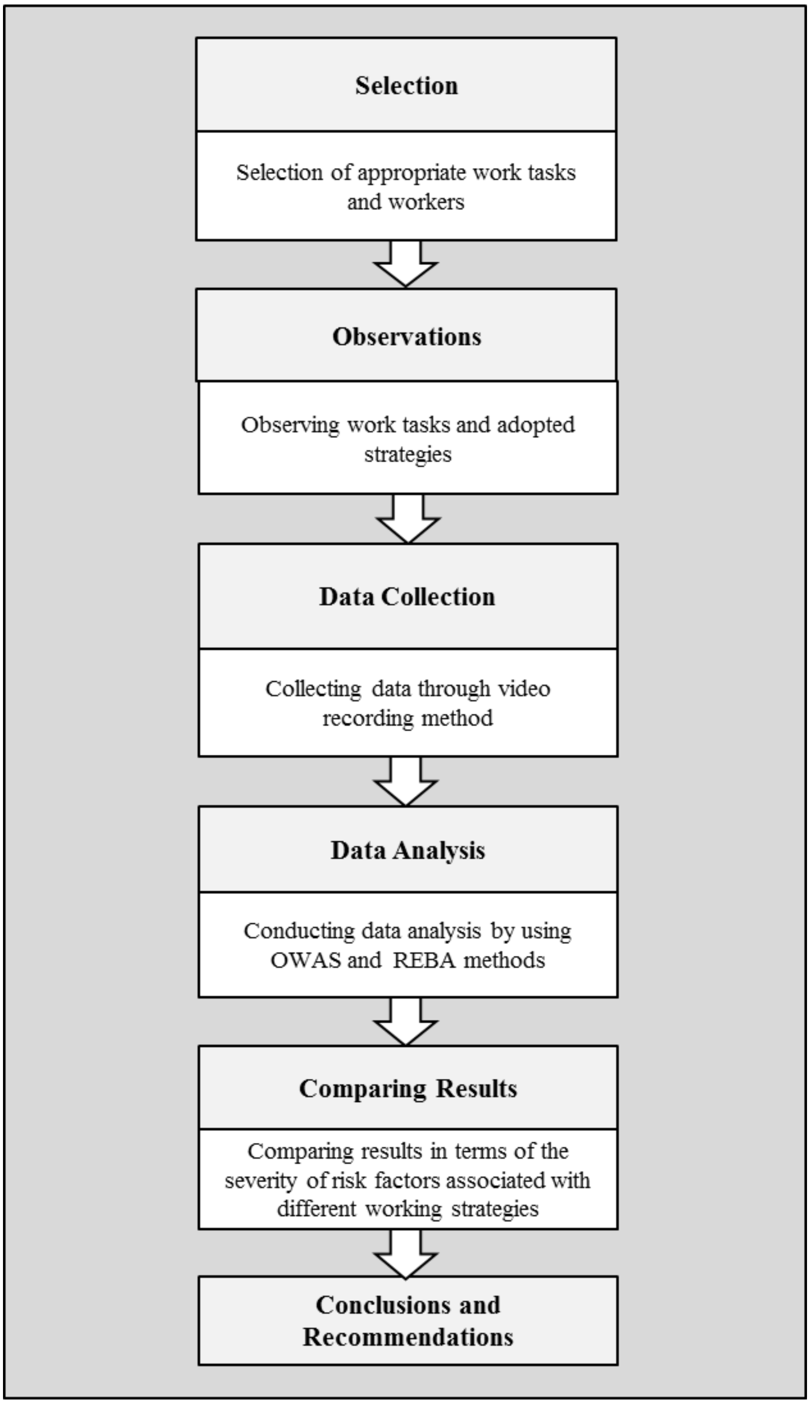

Figure 1: Flow diagram: Method of study for designing inclusive work practices using ergonomic risk assessment methods

2.1 Selection of appropriate work tasks and workers

The objective of quantifying the level of risk attached with any adopted work strategy and variations in working behaviours caused by a number of individual factors can only be achieved by an appropriate selection of work tasks and workers. Inappropriate selection of tasks and workers may lead to unrealistic and inapplicable findings and limit the benefits.

2.2 Observations

Pilot studies should be used to determine the suitability of the proposed data collection method, observing workers in the actual working environment and recording their tasks for a short time. Group discussions and interviews can be used to explore the difficulties and problems of the workers with their current work practices, possible causes of injuries and illnesses and their suggestions for work practice improvements. These group discussions and interviews also help in developing a friendly and participatory observational environment.

2.3 Data collection

Several methods of data collection are possible but video recording has many advantages including the ability to carry out analysis after the event and its relatively unobtrusive nature which does not disturb work patterns. Selection of the workers and the tasks to be observed will be dependent on the objectives of the study and the particular circumstances of the industry being studied.

2.4 Data analysis

This step contains an in-depth analysis of all data collected in the form of videos and still frames of workers performing tasks in the actual working environment. After watching the recorded videos and still frames, differences in working strategies for the same task elements can be observed. Comparison of different task performing strategies in terms of effective time utilization and the level of risk attached can be made through established ergonomic evaluation criteria, including OWAS and REBA.

2.5 Identification of awkward working postures and comparison of results

The results from the observational study identify the levels of risk involved with the adopted postures and the final action categories of OWAS and REBA provide guidelines about which body segment is suffering discomfort. The level of action category in both methods gives guidelines to the observer as to whether or not any adopted working strategy is harmful and, if it is harmful, what level of urgency is demanded.

2.6 Recommendations for an optimal working strategy

The method is concerned with individual working strategies for particular task elements which are captured for ergonomics risk assessment. After identifying awkward working postures, it is straightforward to conclude which methods are more appropriate and safe. Furthermore, the least harmful working method can be taken as a recommended working strategy. This selected method can further be improved using fundamental ergonomics principles and corrective actions could be changes in working posture, working procedure, process sequence and load handling strategy.

3. A case study in a furniture manufacturing factory

3.1 Selection of appropriate work tasks and workers

A total of twelve subjects from a furniture assembly factory participated in this study. They were categorized as specialized (4), multi-skilled (4) and semi-skilled (4) on the basis of their work output, rated by experts who were experienced in determining work performance during a work standardization process. Specialized workers were specialized at their work and always achieved a work performance rating of at least a 100. Multi-skilled workers achieved the desired output and had a work performance of at least 100 at different workstations. Semi-skilled workers had consistently low performance with a rating of less than 100.

A sofa assembly activity was selected to monitor differences in work strategies and all subjects were in good health and had no mobility problems. The appropriate selection of work tasks was important as low difficulty tasks might not show variations in working methods caused due to skill variations. Four workstations were selected where furniture manufacturing assembly tasks of a reasonable level of complexity were performed.

3.2. Observations

Working strategies were observed in a pilot study so that the suitability of the proposed data collection method could be evaluated. During this step, workers were observed and recorded for a short time while they were working in the real working environment. The needs of the experimental setup were investigated and modified accordingly. Three group discussions sessions and interviews with workers were carried out as part of the pilot study. During each discussion session 5-7 workers from the manual assembly lines participated and provided feedback about WMSDs and highlighted their effects. The most common effects mentioned by the workers were back and neck pain, stress on feet, and minor injuries to their fingers. Furthermore, the troublesome workstations were highlighted, helping in the selection of appropriate work stations so that useful evidence (on the relationship of skill and risk of work-related musculoskeletal disorders) could be collected. Some participants were interviewed separately to gain more clarity. This exercise also helped in developing a healthy cooperation among the stakeholders and it was made clear that the data would only be used for improving workplace safety.

3.3 Data collection

Data collection consisted of video recording the selected workers performing a variety of tasks at different work stations. All workers (12) with different levels of skill (4 in each of the three categories) were recorded on 4 work stations. Each worker was recorded at least 4 times performing the same task elements. An appropriate distance between the recording device (camera) and worker was maintained so that working postures and process sequences could be clearly observed, and a few of the more complex activities were recorded from different angles.

3.4 Data analysis

The recorded videos and still frames were studied and differences in working strategies for the same task elements were observed. Comparison of different task performing strategies in terms of effective time utilization during manual object handling activities and the level of risk attached was made using established ergonomics evaluation methods. Over 700 static video frames were selected for analysis purposes and the OWAS and REBA methods were applied for risk assessment. The purpose of using these two techniques was to verify the results and conclusions from both techniques so that a better understanding could be developed. As an example of the application of the OWAS method consider the posture adopted by the worker in the left-hand part of figure 2. By reference to table 2, the back is straight (back code 1), one arm is above shoulder level (arm code 2), the worker is standing on both legs (leg code 2) and the load is less than 10kg (load code 1). The overall code is thus 1221 and the action code is as highlighted in table 6.

Table 6: Determination of action code from posture analysis

Back	Arms	1			2			3			4			5			6			7			Legs
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Load
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	**1**	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

The first line of table 4 confirms that an action category of 1 is ‘a normal and natural posture with no harmful effect on the musculoskeletal system – no action required’.

3.5 Identification of the awkward working postures and results comparison

The observational study identified the level of risk involved with adopted postures and the final action categories of OWAS and REBA provided indications as to which body segment was suffering discomfort. The level of action category in both methods gives guidelines to the observer as to whether or not any adopted working strategy is harmful and if it is harmful, what level of urgency it demands.

3.6 Recommendations for an optimal working strategy

As mentioned earlier, this study included a variety of workers whose individual working strategies for a particular task element were captured and an ergonomics risk assessments were carried out. After identifying awkward working postures, the observer could readily determine which method was more appropriate and safe. The least harmful working method could be taken as a recommended working strategy, which could be further be improved by applying fundamental ergonomics principles. Corrective actions can be a change in working posture, working procedure, process sequence, load handling strategy and smart movements of body parts.

4. Results

The overall analysis can be divided into two categories:

- Object handling strategies
- Postural assessment

4.1 Object handling strategies:

A significant variation in object handling strategies was found during the analysis. Recorded videos were analysed to assess how object handling methods vary with changes in working skills. It was observed that semi-skilled workers faced greater difficulties in manual handling and their working methods were found to have a high level of risk.

Table 7 shows the frequency with which specialized, multi-skilled and semi-skilled workers moved the object during one complete cycle on different workstations. It is evident from the table that variations in the levels of skill greatly affected object handling strategies. For example, at workstation 1, with the same task element, a specialized worker rotated the sofa only twice during one cycle, whereas, the multi-skilled worker made 6 changes and the semi-skilled worker 11 changes, In addition to wasted time in orientation changes, the sofa was a heavy and physical handling demanded considerable effort and adoption of awkward postures.

Table 7: Comparing object handling strategies; the number of rotations

	Workstation 1	**Workstation 2**	**Workstation 3**	**Workstation 4**
Specialized workers	2	2	3	2
Multi-skilled workers	6	2	4	3
Semi-skilled	11	5	2	5

workers				

A few frames from the videos are shown in figures 2, 3 and 4;, and show the differences in object handling strategies adopted by different workers on the same workstation (workstation 1) for the same activity. Specialized workers changed the position of the sofa only twice; firstly, when it was received from the previous workstation so as to position it vertically at an appropriate distance from the body, and finally at the completion of the work. Subsequent frames show the difficulties faced by multi-skilled and semi-skilled workers.

Figure 2: Specialized worker’s object handling strategies

Figure 3: Multi-skilled worker's object handling strategies

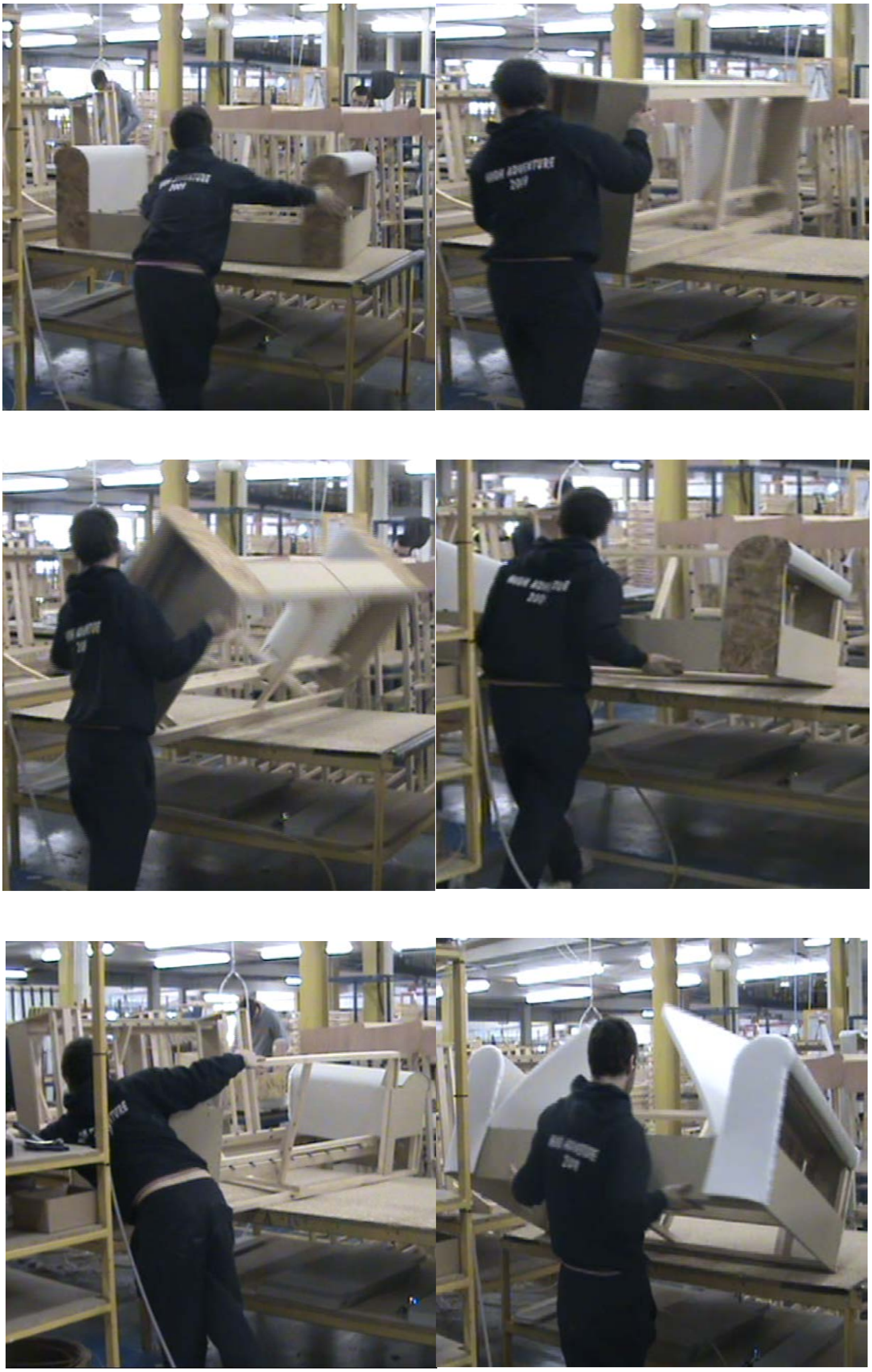

Figure 4: Semi-skilled worker’s object handling strategies

4.2 Postural assessment

Postural assessment was carried out by using two observational techniques; the OWAS and REBA methods.

4.2.1 OWAS results

The OWAS postural assessment results clearly indicate that specialized workers are more likely to adopt relatively safer working strategies as compared with multi-skilled and semi-skilled workers but the same is not true at workstation 3 where a semi-skilled worker performed exceptionally well. Moreover, it's quite clear that the workplace needs a significant level of attention for improving working strategies of assembly workers as a whole. The overall results can be summarized as:

- Approximately 33% of the total postures required corrective actions soon or immediately (as they belong to action categories 3 and 4), indicating that this is not a very safe place to work (figure 5)
- The percentage of postures belonging to action categories 1 and 2 is the highest for specialized workers who have lower occurrences of action categories 3 and 4 (figure 6). These trends indicate that specialized workers are more likely to complete their work with relatively less harmful working body postures, as compared with multi-skilled and semi-skilled workers. Surprisingly, the semi-skilled worker at workstation 3 is exceptionally good in terms of his exposure to risk (figure 7 and 8).
- The results shown in table 8, indicate that the following positions of different body parts are the major causes of risk attached with the working strategies:
    - Back – bent and twist
    - Legs – standing or squatting on both feet with knees bent
    - Arms – one arm at or above shoulder level
    - Load – Load > 50kg

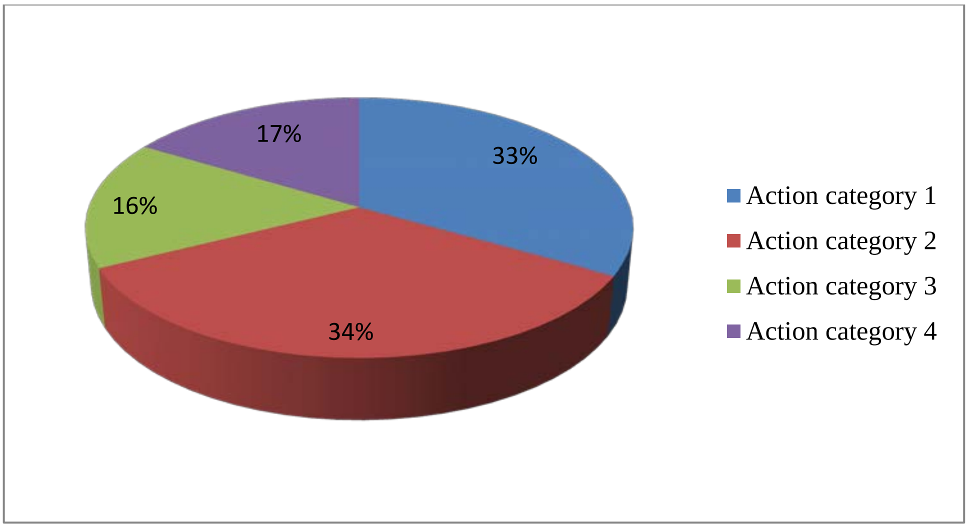

Figure 5: Showing OWAS overall workplace risk assessment results

Figure 6: Showing OWAS overall workplace risk assessment results for workers of different level of skills

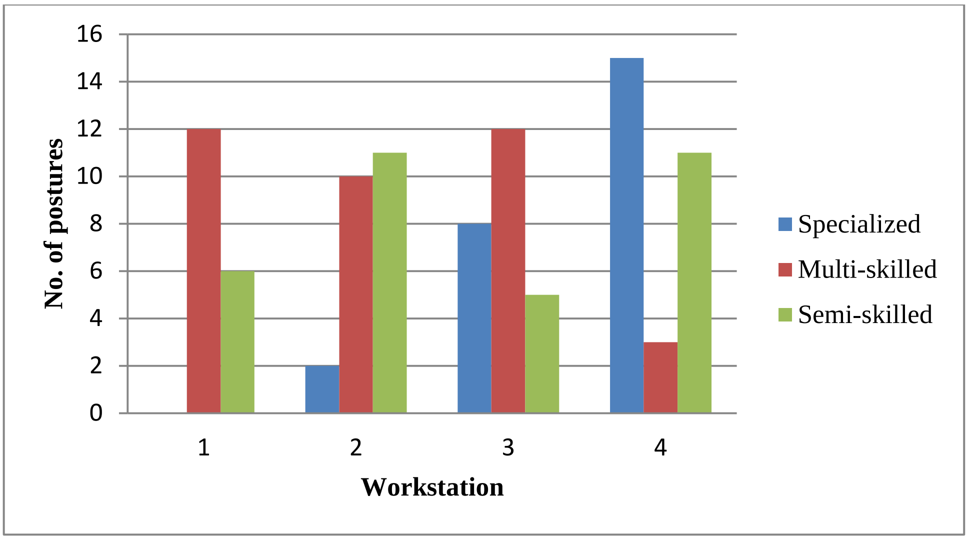

Figure 7: Showing OWAS skill and workstation based risk assessment results

(Action category 4)

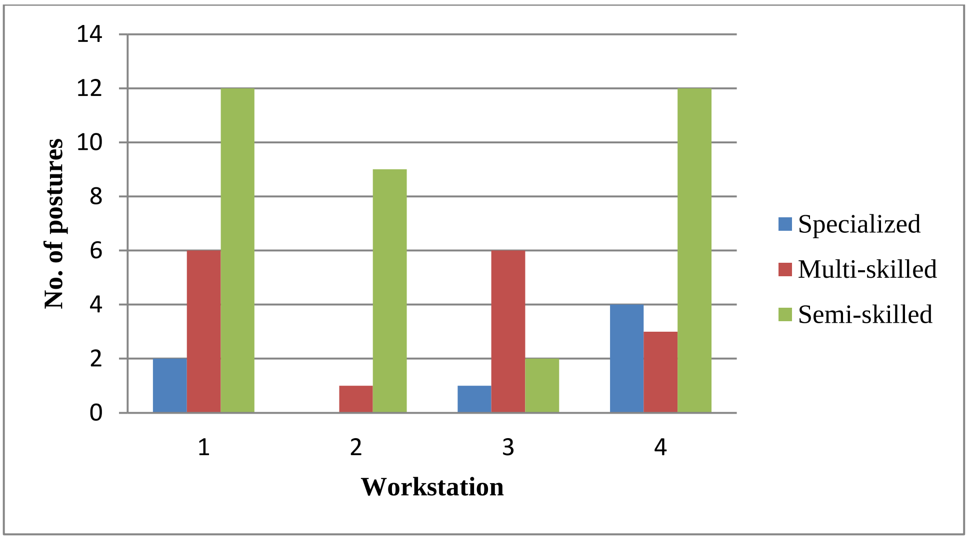

Figure 8: Showing OWAS skill and workstation based risk assessment results

(Action category 3)

Table 8: Accessing prevalence of postures that are more harmful and major causes of risk exposure through the OWAS method

Posture Category	**Description**	**Percentage of postures in action categories 3 & 4**
Back posture code 4	bent and twist	67.3
Arms posture code 2	one arm at or above shoulder level	27.4
Legs position codes	standing or squatting on	63.3

3 and 4	both feet with knees bent	
Load carrying code 3	load > 20kg	34.1

4.2.2 REBA results

The REBA results also highlight similar relationships between level of skill and risk exposure as found by the OWAS method. The results can be summarized as:

- The workplace is not a safe place to work, as about 50% of the postures require corrective action soon or immediately (action categories 3 and 4), shown in figure 9.
- In general, semi-skilled workers and multi-skilled workers are more likely to adopt risky postures as compared with specialized workers. However, a semi-skilled worker at workstation 3 was exceptionally good and adopted relatively less risky postures as compared with other semi-skilled workers on workstations 1, 2 and 4 (figures 10, 11 and 12).
- The following posture categories (table 9) contributed significantly in exposing workers to the risk of injury:
    - ➢ Trunk – side flexed and twisted
    - ➢ Neck - $>20^0$ flexion/extension and side flexed
    - ➢ Leg positions – unilateral/bilateral weight bearing with knees flexion
    - ➢ Load – high load carrying
    - ➢ Upper –arm – High level of arm flexion with abduction, rotation or raised shoulder positions
    - ➢ Wrist – flexion with deviation and double movements

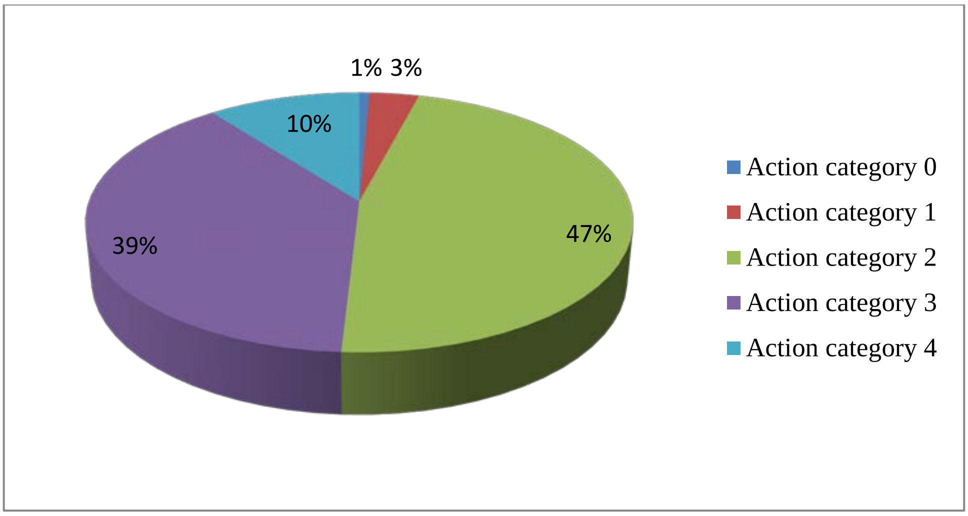

Figure 9: REBA overall workplace risk assessment results

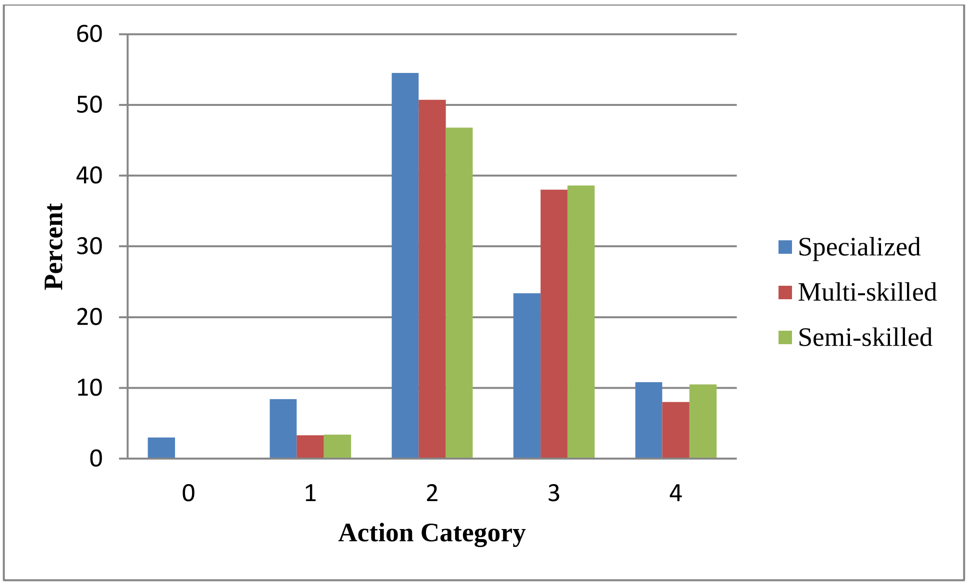

Figure 10: REBA workplace risk assessment results for workers with different level of skills

Figure 11: REBA skill and workstation based risk assessment results (Action Category 4)

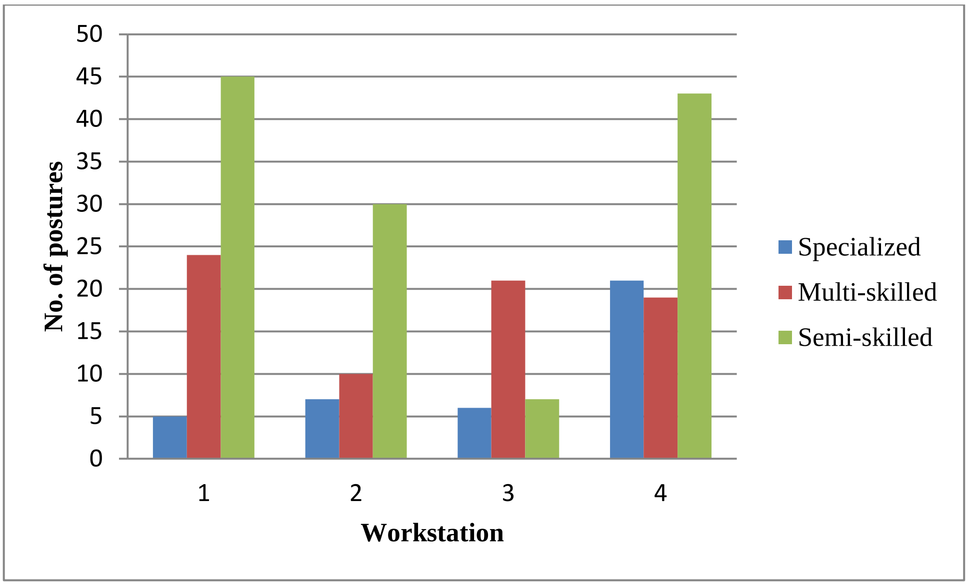

Figure 12: REBA skill and workstation based risk assessment results (Action Category 3)

Table 9: Prevalence of postures that are harmful and potentially leading to risk exposure (REBA)

Posture category	**Description**	**Percentage of postures in action categories 3 &4**
Trunk position Code 3 and 4	Different combinations include 0^0-20^0, 20^0-60^0, >60^0 flexion/extension and side flexed or twisted	63.5
Neck position code 2 and 3	Three possible combinations of 0^0-20^0 flexion/extension, >20^0 flexion/extension and side flexed movement	93.6
Legs position code 3	Unilateral/bilateral weight bearing with knee flexion	30.4
L/F carrying code 2	>10kg	21.7
Upper arm position code 4 and 5	Different combinations include >90^0 flexion, 45^0-90^0 flexion with abduction, rotation or raised shoulder position	74.5
Lower arm position code 2	<60^0 flexion or >100^0 flexion	66.7
Wrist position code 3	>15^0 flexion/extension with deviation and twist	81.1

4.2.3 Comparison of OWAS and REBA results:

REBA categorizes actions into 5 levels (0-4), whereas OWAS categorizes into 4 levels (1-4). For comparison purposes, REBA action categories 0 and 1 are combined as they are very similar in terms of level of severity. It can be concluded from figure 13 that OWAS predicts fewer severe risk postures (3 and 4) as compared with REBA. OWAS predicts that 33.3% of working postures belong to action category 1 which is significantly higher than REBA (which is only about 4.1%, shown in figure 13, table 10). On the other hand, for action categories 2 and 3, OWAS highlights significantly fewer postures and the trend is more prominent for action level 3 where it shows only 16% (113) postures as compared with 38.6% (272). Another study conducted by Kee and Karwowski (2007), compared three observational techniques OWAS, REBA and RULA, and reported similar findings when results between OWAS and REBA are compared with each other (Kee and Karwowski, 2007).

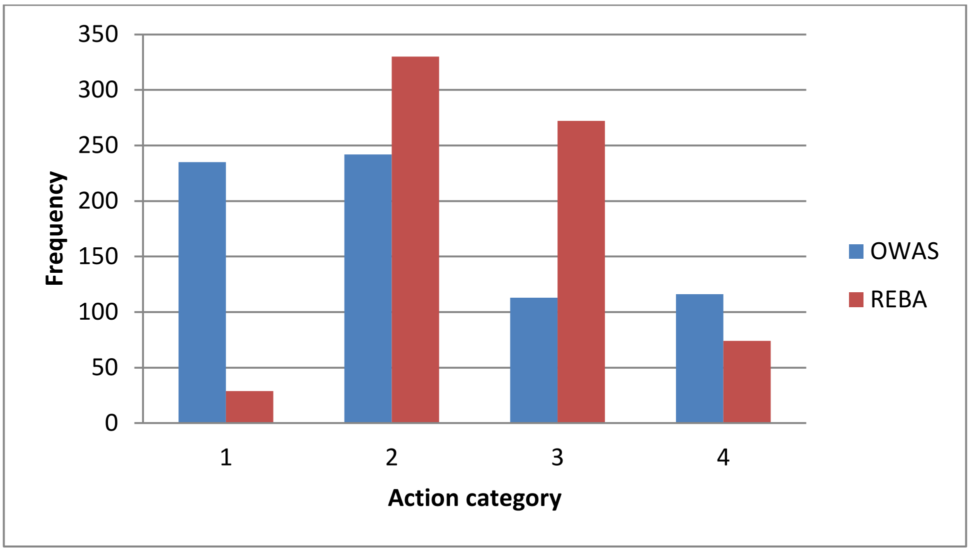

Figure 13: Comparison of OWAS and REBA postural analysis results

Table 10: Comparing OWAS and REBA results for different action categories

Action Category	REBA		OWAS	
Action Category	**Frequency**	**valid percent**	**Frequency**	**valid percent**
0	5	0.7	Not valid	Not valid
1	24	3.4	235	33.3
2	330	46.8	242	34.3
3	272	38.6	113	16.0

4	74	10.5	116	16.4

The objective of using both observational risk assessment techniques was only to verify the relationship between the individual factor under observation (skill) and risk exposure associated with different working strategies. It was revealed that both techniques demonstrate a similar kind of relationship between this individual factor and the level of risk involved with work strategies. All 4 workstations were analysed and table 11 shows the number of postures recommended for action categories 3 and 4 for each workstation and workers with different levels of skill, by both OWAS and REBA. It is very clear that semi-skilled workers are more vulnerable to risk factors associated with their work as compared with specialized and multi-skilled workers and this trend is highly visible in action level 3 results for both OWAS and REBA (table 11).

Furthermore, tables 12 and 13 also feature similar results, leading to the conclusion that skill plays an important role in prevention of hazardous working conditions

Table 11: Comparison of OWAS and REBA results, number of postures for action categories 4 and 3

Action Category 4 (Risk level is very high, action is necessary now)									
REBA	**Workstation**				**OWAS**	**Workstation**			
	1	2	3	4		1	2	3	4
Specialized	5	0	8	4	Specialized	0	2	8	15
Multi-skilled	3	1	7	4	Multi-skilled	12	10	12	3
Semi-skilled	8	10	2	13	Semi-skilled	6	11	5	11
Action Category 3 (Risk level is high, action is necessary soon)									
REBA	**Workstation**				OWAS	**Workstation**			

	1	2	3	4		1	2	3	4
Specialized	5	7	6	21	Specialized	2	0	1	4
Multi-skilled	24	10	21	19	Multi-skilled	6	1	6	3
Semi-skilled	45	30	7	43	Semi-skilled	12	9	2	12

Table 12: Results for different action categories by level of risk – OWAS method

OWAS		**Valid percentage**			
Action Category	**Frequency**	**Overall**	**Specialized**	**Multi-skilled**	**semiskilled**
1	235	33.3	38.7	34.4	29.8
2	242	34.3	40.5	30.2	33.7
3	113	16	9.5	14.2	20.6
4	116	16.4	11.3	21.2	16.0

Table 13: Results for different action categories by level of skill – REBA method

REBA		**Valid percentage**			
Action Category	**Frequency**	**Overall**	**Specialized**	**Multi-skilled**	**semiskilled**
0	5	0.7	3.0	0.0	0.0
1	24	3.4	8.4	3.3	3.4
2	330	46.8	54.5	50.7	46.8

3	272	38.6	23.4	38.0	38.6
4	74	10.5	10.8	8.0	10.5

5. Discussion

Different workers adopt different working strategies and these differences significantly affect the level of risk of musculoskeletal disorders. In this study workers of varying skill were analyzed and it was found that workers with high levels of skill are better in the adoption of relatively safe and productive working strategies. So, it can be concluded that increasing skill levels through training and experience reduce the chances of musculoskeletal disorders because well-trained workers adopt easy and safe working methods. These findings reveal that human variability issues are directly linked with individual and organizational work performance, so these issues must be highlighted and solved during any work standardization process. Selection of optimized working procedures and then training the workforce accordingly is a key to success where workers with their existing differences can perform in an equally productive way. Moreover, it was also found that load handling is the key area that causes wastage of time and is a major cause of risk for less skilled workers. Non-value added time can be significantly decreased by avoiding unnecessary movements of objects, which lead to awkward body postures. This evidence provides an opportunity to understand the human variability issues regarding working patterns and their effects on work performance. It also throws light on how varying levels of skill are linked to work safety and productivity. Understanding and anticipating human differences and their relationships with workplace safety and human well-being, is considered to be a potential way to address future workforce challenges. Finally, the framework given in this article has been found useful as it helps in highlighting variability issues, their relationship with individual factors and ultimately developing a linkage between individual factors and workplace safety by exploring the effects of individual factors on the level of risk attached with any adopted working method. This method also highlights the major causes that create a hazardous working environment and how these causes can be eliminated by minimizing human variations where results gathered through the case study can be used to promote inclusive, safe and easy work practices that are equally acceptable and productive. This research contributes at the individual as well as at the organizational level, where its benefits can be seen in terms of employee satisfaction, workplace safety (fewer injuries and disorders) and high productivity and quality (high value-added time and relaxed working environment).

The use of the ergonomic risk assessment methods suggested in this article, provides useful information about how individual factors such as skill influence task performing strategies and identify the major causes of risk associated with these adopted strategies. The findings of the research can be used to train the workforce for the promotion of more standardized work practices that are both safe and acceptable. The methods can potentially prevent work-related musculoskeletal disorders, injuries, pains and discomfort and consequently increase individual and organizational work performance leading towards better accommodation and retention of employees.

6. Conclusion

The following conclusions can be made from this study:

- Different workers adopt significantly varying working strategies, and these differences affect the risk of musculoskeletal disorders
- Workers with high levels of skill are better in the adoption of relatively safe and productive working strategies, whereas less skilled workers are more vulnerable to risk factors at their work because of their poor working strategies.
- Manual load handling is the key area that is a major cause of workplace risk for less skilled workers. Training on manual material handling strategies would be a useful strategy for the promotion of safe and productive work practices.
- The proposed framework based on using the ergonomic risk assessment methods like OWAS and REBA can be used for understanding the effects of individual factors (skill in this case) on task performing strategies and quantification of level of risk attached.
- Comparison of OWAS and REBA postural assessment results shows that both methods are useful in understanding human variability issues and their relationship with workplace safety

and productivity as both indicated the same relationship between skill and musculoskeletal disorders.

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