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HEALTH & SAFETY LABORATORY

Benchmarking of the Manual Handling assessment Charts (MAC)

HSL/2002/31

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OBJECTIVES

To benchmark the Manual handling Assessment Charts (MAC) developed by HSL/HSE against existing tools used for risk assessment of manual handling operations. The Quick Exposure Check (QEC), Rapid Entire Body Assessment (REBA), Ovako Working posture Analysis System (OWAS) and the 1991 NIOSH lifting equation were used.

MAIN FINDINGS

(1) Measuring exposure to musculoskeletal risk factors is both conceptually and practically complex and a wide variety of methods of assessing risk from manual handling have been developed and described in the scientific literature. Most of these risk assessment tools rely on snapshot assessments of single postures, often those believed to be hazardous or problematic. Time-sampling and weighting of measurements are possible but time-consuming and offer further difficulties in interpretation.

(2) There are clear links between the methods reviewed, with concepts and scoring systems from previous methods being reused, often in modified forms, in later methods. The status of the different tools is variable, with further work on the QEC still underway. The amount of validation of any form on any of the tools is still quite small and none have been formally validated as predictors of risk of injury or sickness absence.

(3) A benchmarking exercise was carried out by a small number of ergonomists who used five risk assessment tools to assess five tasks. The MAC was ranked as one of the easiest to use and one of the most appropriate methods for assessing manual handling operations. There were no systematic differences in how the different methods ranked the levels of risk of the tasks studied but the way that the severity of tasks was ranked was random. The tools appear to be assessing risk in different ways and so cannot be compared easily.

(4) The conceptual model on which the MAC is based assumes that risk values due to separate factors can be added and that there are no interactions between the factors except for load and frequency of handling. OWAS, REBA and the QEC use ordinal scoring systems and then combine the scores for different risk factors. OWAS and REBA were designed to produce an assessment of the urgency of remedial action for the task being assessed using "Action Categories".

(5) The QEC has an exact mathematical model implicit in its structure. Recently, Action Levels have been proposed based on the total score across all parts of the body. The adoption of this approach is unfortunate because it confuses risk across different parts of the body.

(6) The 1991 NIOSH lifting equation is based on a parametric multiplicative model of risk relative to a reference load of 23 kg lifted under ideal circumstances. The focus is the task not the posture of the individual. It is possible to convert the NIOSH equation into an additive model but the form is quite different to those underlying the MAC and the QEC due to it calculating a relative risk. Both additive and multiplicative models are theoretically valid approaches to the issue of assessing risk of manual handling. However, the lack of epidemiological validation means that the accuracy of the scoring systems is unknown. The MAC seeks to assess when an individual risk factor is beyond safe limits without

attempting to assign an overall risk level to the whole task and is therefore a much sounder basis for risk assessment than methods that seek to assess the overall risk since any real job is likely to contain several independent risks.

(7) There is therefore a clear need for risk assessment tools to distinguish between risk to the low-back and risks to the upper limbs. Both REBA and the QEC are flawed because they create overall scores from a mixture of risk factors specific to the upper limb and specific to the low back. The MAC is focussed on the risk of injury to the low back from manual handling and does not attempt to score risk to the upper limb.

RECOMMENDATIONS

HSL is currently running a longitudinal study to test the ability of the NIOSH equation to predict work absence due to low back pain caused by workplace lifting operations. Once this project has been completed the data collected should be used to test the ability of the MAC to predict this outcome.

1 INTRODUCTION

1.1 BACKGROUND

Prevention and control of work related musculoskeletal disorders (WRMSDs) is one of the Health and Safety Commission's (HSC) priorities. Success in this area is vital if the targets in *Securing Health Together* (HSC, 2000) of reducing by 2010 the incidence of work-related ill health by 20% and reducing the number of work days lost due to work-related ill health by 30%.

Health and Safety Executive (HSE) and local authority inspectors enforce health and safety law, and provide advice on risk factors and control measures on a wide range of health and safety issues. Therefore, they need to be able to quickly identify high risk activities likely to cause WRMSDs. However, it can be particularly difficult to establish the degree of risk in relation to WRMSD because of the lack of quantitative exposure-response relationships, the wide range of risk factors, and the interactions between them.

Risk assessment is fundamental to the hierarchy of controls specified in the 1992 Manual Handling Operations Regulations. Therefore, a concern of HSE is to ensure that suitable and sufficient methods of risk assessment are available for duty holders to use. As an enforcing authority, HSE has to provide guidance for its field professionals in determining whether a particular work activity, such as a manual handling operation, poses a significant risk of injury to the workers performing it.

1.2 AIMS AND OBJECTIVES

The Ergonomics Section of HSL has worked on behalf of, and in co-operation with, the Human Factors Unit of HSE's Health Directorate, and with other Divisions and Directorates within HSE, to develop a risk assessment tool for HSE inspectors to use when inspecting premises where manual handling operations are carried out by the workforce.

The tool is known as the Manual handling Assessment Charts (MAC). It focuses on manual handling operations involving lifting by individuals, lifting by teams of up to four people, and carrying by individuals. Monnington *et al*. (2002) reported the development of the tool from its initial conceptualisation up to its formal release to HSE inspectors in November 2002. Testing of the usability of the tool is reported by Care *et al*. (2002); testing of the reliability is reported by Tapley (2002).

The purpose of this document is to report an exercise undertaken to benchmark the MAC by comparing it with existing tools used for risk assessment of manual handling operations.

2 EXTANT TOOLS FOR ASSESSING RISK OF WORK-RELATED MUSCULOSKELETAL DISORDERS

Tables 1 and 2 summarise a number published methods of assessing risk of WMSDs for manual handling operations.

2.1 THE HSL/HSE MAC

These are the flowcharts being benchmarked in this study. Attention is focussed primarily on the Lifting flowchart, but many of the factors in the Team Handling and Carrying flowchart are common to it.

2.2 THE 1991 NIOSH REVISED LIFTING EQUATION

This is a revision of the 1981 NIOSH Lifting Equation. It was developed by the National Institute of Occupational Safety and Health in the USA. It is a multiplicative equation that uses parameters of the job to predict a Recommended Weight Limit which is believed to be safe for most workers to handle (Waters *et al*., 1994, NIOSH 1981).

2.3 THE QUICK EXPOSURE CHECK (QEC)

This was developed by the Robens Institute at the University of Surrey with funding from HSE. Its purpose is to be a user friendly practical tool for the assessment of physical exposure to risks for work-related musculoskeletal disorders (Li and Buckle, 1999).

2.4 RAPID ENTIRE BODY ASSESSMENT (REBA)

This was developed as a postural analysis tool to be sensitive to the type of unpredictable working postures found in health care and other service industries (Hignett and McAtamney, 2000). Its approach and scoring system are clearly based on RULA (Rapid Upper Limb Assessment) (McAtamney and Corlett, 1993).

2.5 SNOOK PSYCHOPHYSICAL TABLES

These are tables of maximum acceptable weights and forces for a variety of manual handling operations, including lifting, lowering, pushing and pulling. They are based on extensive experiments using industrial workers adjusting the loads being handled until they had selected loads that they considered they could handle for the duration of a work shift without excessive strain or fatigue (Snook and Ciriello, 1991; Snook, 1978).

2.6 2D AND 3D SSPP

These are two-dimensional and three-dimensional linked segment models of the human body that can be used to predict the percentage of the industrial population that can exert a specified force at the hands in a specified static posture (Chaffin, 1969; Garg and Chaffin, 1975; Chaffin *et al.*, 1987; Chaffin, 1988; Chaffin and Erig, 1991).

2.7 OWAS

This is a method of coding the posture of a worker that allows the harmfulness of the posture to be categorised into four Action Categories of increasing urgency. It is based upon expert judgements of the harmfulness of particular postures. A time-based sampling approach can be used with it so that the categorisation can take account of the length of time spent in any particular posture (Karhu *et al.*, 1977, 1981, Kivi and Mattila, 1991, Vedder, 1998).

2.8 PEO

This is a method of continuously recording postures and manual handling operations in real time on a portable computer. It allows durations and numbers of manual handling operations and occurrences of particular postures to be calculated. The aim is to produce an estimate of the typical weekly exposure to physical stress from manual handling and posture (Fransson-Hall *et al.*, 1995; Karlqvist, 1994; Leskinen, 1997).

2.9 PLIBEL

This is a "method for the identification of musculoskeletal stress factors that may have injurious effects". It consists of a checklist designed to help experienced observers with screening workplaces for risk factors. Hazards are linked to five body areas (Kemmlert, 1995).

2.10 RODGERS' JOB ANALYSIS

This is a method of evaluating the physiological demands of a task against published criteria of acceptable levels of oxygen consumption for whole body or upper body work (Rodgers, 1997; Rodgers and Yates, 1990; Rodgers, 1978).

Table 1 Extant manual handling risk assessment tools (a)

	MAC	*NIOSH*	*QEC*	*REBA*	*Snook psycho-physical tables*
Date	2002	1981, 1991	1999	2000	1977, 1991
Output	Risk score	Lifting Index	Action Levels	Action Levels	Maximum Acceptable Weight of Lift (MAWL)
Output type	Additive	Multiplicative	Sum of scores	Ordinal codes	Weight acceptable to workforce %age
Quantitative?	Semi	Yes	Semi	No	Yes
Underlying data	Snook	Snook, Garg, Herrin	None	None	Own
Injury focus	Low back	L5/S1	WMSDs	WMSDs	N/A
Types of MHO	Lift, carry, team lift	Lifting, lowering	All	Health care tasks	Lift, lower, push, pull, carry
Sampling	One off	One-off	One-off	One-off	One-off
Assessment	Task, posture, environment	Task	Posture	Posture	Task
Load/force	Yes	Yes	4 categories	4 categories	Yes
Start height of lift	5 categories	Yes	3 categories	NA	3 ranges
End height of lift	No	Yes	NA	NA	No
Horizontal hand distance	Yes	Yes	NA	NA	3 object depths
Distance of lift	No	Yes	NA	NA	Yes
Object size	NA	NA	NA	NA	Yes
Frequency	Lifts per minute	Lifts per minute	3 categories	2 categories	Lifts per minute
Duration/recovery	No	Yes	3 categories	2 categories	No
Quality of grip	3 categories	3 categories	NA	4 categories	NA
Floor surface	3 categories	NA	NA	NA	NA
Other environ-mental factors	3 categories	NA	4 categories	NA	NA
Neck flexion	NA	NA	3 categories	2 categories (3 with lateral flexion)	NA
Neck rotation	NA	NA	3 categories	4 categories	NA
Trunk flexion	Combined with horizontal reach	NA	3 categories	4 categories	NA
Trunk asymmetry	Trunk twisting / sideways bending	Task asymmetry	Combined with trunk flexion	2 categories	NA
Upper arm posture	Combined with horizontal reach	NA	3 categories	6 categories	NA
Forearm posture	NA	NA		2 categories	NA
Hand/wrist posture	NA	NA	2 categories	3 categories	NA
Leg posture/actions	NA		NA	4 categories	NA
Factor interactions	No	No	Yes	Yes	No

Table 2 Extant manual handling risk assessment tools (b)

	2D and 3D SSPP	*OWAS*	*PEO*	*PLIBEL*	*Rodgers Job Analysis*
Date	1969-1991	1977	1995	1995 (1986)	1960-1997
Output	% capable	Action Categories	No single metric	Checklist	Rate of oxygen consumption (VO_2)
Output type	Prediction	Ordinal codes	NA	Dichotomous	Measured
Quantitative?	Yes	No	No	No	Yes
Underlying data	Chaffin	None	None	AET	Astrand, Rodhal, Rodgers
Injury focus	Range of joints	Musculoskeletal system		Whole body in 5 regions	Whole body fatigue
Types of MHO	Static sagittal plane and 3D exertions	All	All	All	Dynamic whole body
Sampling	One-off	Time lapse or continuous	Continuous	One-off	Representative period
Assessment	Strength	Posture/load	Posture/force	Posture	VO2
Load/force	Measured	3 categories	4 categories	2 categories	NA
Start height of lift	Yes	NA	NA	3 categories	Back vs. arm work
End height of lift	NA	NA	NA	3 categories	Back vs. arm work
Horizontal hand distance	Yes	NA	NA	2 categories	NA
Distance of lift	NA	NA	NA	NA	NA
Object size	NA	NA	NA	NA	NA
Frequency	NA	NA	Yes	NA	Lifts/min
Duration/recovery	NA	NA	Yes	NA	Yes
Quality of grip	NA	NA	NA	2 categories	NA
Floor surface	NA	NA	NA	2 categories	NA
Other environ-mental factors	NA	NA	NA	Space, tools	Temperature
Neck flexion	NA	NA	2 categories	3 categories	NA
Neck rotation	NA	NA	2 categories	3 categories	NA
Trunk flexion	Yes	2 categories (3 with trunk rotation)	3 categories	3 categories	NA
Trunk asymmetry	No (2D) Yes (3D)	2 categories (3 with trunk flexion)	2 categories	3 categories	NA
Upper arm posture	NA	NA	NA	NA	NA
Forearm posture	NA	NA	NA	NA	NA
Hand/wrist posture	NA	3 categories related to shoulder height	3 categories related to shoulder height	2 categories	NA
Leg posture/actions	NA	7 categories	2 categories	4 categories	NA
Factor interactions	No	No	Yes	No	?

3 BENCHMARKING OF THE MAC

3.1 APPROACH ADOPTED

A small number of the existing assessment methods listed in Tables 1 and 2 were selected for detailed comparison with the MAC. These were:

- The Quick Exposure Check (QEC)
- Rapid Entire Body Assessment (REBA)
- Ovako Working posture Analysis System (OWAS)
- The 1991 NIOSH Revised Lifting Equation

A small number of ergonomists experienced in assessing industrial manual handling tasks used the five methods to assess five single-person manual handling tasks (Table 3). This was done using video clips to ensure that the information presented to each expert was consistent. Information was given on weights and frequencies and durations of handling where these could not be observed from the video.

Table 3 Tasks used for benchmarking of the risk assessment tools

Task	*Description*	*Weight*
A	Transfer of compost bale, slicing packaging and tipping into hopper	50 kg
B	Removal of welded mesh from machine and transfer to stack	15 kg
C	Picking of cases from pallets onto conveyor	25 kg
D	Picking of cases from pallets onto conveyor	15 kg
E	Loading wire bobbins onto machine	20 kg

They firstly used a four-point scale give a personal expert opinion of the severity of the risk of injury from the manual lifting operations/need for action to reduce it:

(a) No action required

(b) Action required in the near future

(c) Action required as soon as possible

(d) Action required immediately

They then scored each of the tasks using the different manual handling risk assessment tools.

Finally, they were asked to rank the five risk assessment methods for:

(a) Ease of use

(b) Suitability

3.2 ANALYSIS OF RESULTS OF TASK ASSESSMENTS

With the inclusion of the Expert Opinions of each task, six assessments were made of each task. Of these, REBA and the QEC arrive at a score which is then converted into a recommendation for action. This is done on a four- (QEC) or five-point (REBA) ordinal scale, based on that originally used by OWAS. This has the effect of reducing the variability of the scores and therefore of introducing more ties into a ranking system. The QEC total scores were converted into Action Levels using score boundaries recommended by Li (2002b).

Table 4 Types of output from the different risk assessment tools

	Expert opinion	*MAC Total*	*QEC*		*REBA*		*OWAS Action Category*	*NIOSH Lifting Index*
			Total	*Action Level*	*Score*	*Action Level*		
Scale type	Ordinal 4 point scale	Ordinal integer scale	Integer scale	Ordinal 4 point scale	Ordinal scale	Ordinal 5 point scale	Ordinal 4 point scale	Ratio scale

Direct comparison of the "raw" scores provided by the different tools was not possible due to the different types of data returned by the tools (see Table 4 for data types). Therefore, the non-parametric Friedman test was used for statistical analysis. This compares the rank orders of the scores using the χR^2 statistic.

Because four of the tools (Expert Opinion, QEC Action Level, REBA Action Level, OWAS Action Category) were scored using what was effectively the same four-point ordinal scale of urgency of action that originated with OWAS, it was decided to facilitate comparison by converting the MAC scores and the NIOSH Lifting Indices into four point scores described as the MAC Action Category and the NIOSH LI Action Category. This was done using the ranges in Table 5. It was also decided to use the generic term 'Action Categories' (AC) to describe both Action Levels (QEC and REBA) and Action Categories (OWAS, Expert opinion, MAC and NIOSH). The REBA Action Levels of 0 and 1 were combined into Action Level 1 since Action Levels of 0 can occur in only very few circumstances.

Table 5 Action Category boundaries for the MAC and NIOSH

Action Category	*Meaning*	*MAC AC*	*NIOSH LI AC*
1	No action required	$0 \leqslant$ MAC total $\leqslant 4$	$0 \leqslant$ LI < 1
2	Action required in the near future	$5 \leqslant$ MAC total $\leqslant 12$	$1 \leqslant$ LI < 3
3	Action required soon	$13 \leqslant$ MAC total $\leqslant 20$	$3 \leqslant$ LI < 6
4	Action required immediately	$21 \leqslant$ MAC total $\leqslant 31$	$6 \leqslant$ LI

While it was possible to define the NIOSH LI AC in relation to the NIOSH (1981) Action Limit (AL) (LI = 1) and Maximum Permissible Limit (MPL) (MPL = 3 × AL: LI = 3), an arbitrary decision had to be made as to the boundary between the third and fourth Action Categories. With the MAC, all the boundaries between Action Categories are somewhat arbitrary but were chosen to allow a task with only one amber score to fall into Category 1 and equal sizes to Action Categories 2 and 3.

3.3 RESULTS OF BENCHMARKING BY EXPERTS

Four ergonomists completed the exercise to compare the five tools. After validation of the data they were entered into a spreadsheet. It was noted that there were wide discrepancies between the scores recorded by the different individuals. This was partly attributed to a lack of direct experience of some of the tools and to the difficulty of assessing tasks from a short video clip.

3.3.1 Comparison of severity of the five tasks

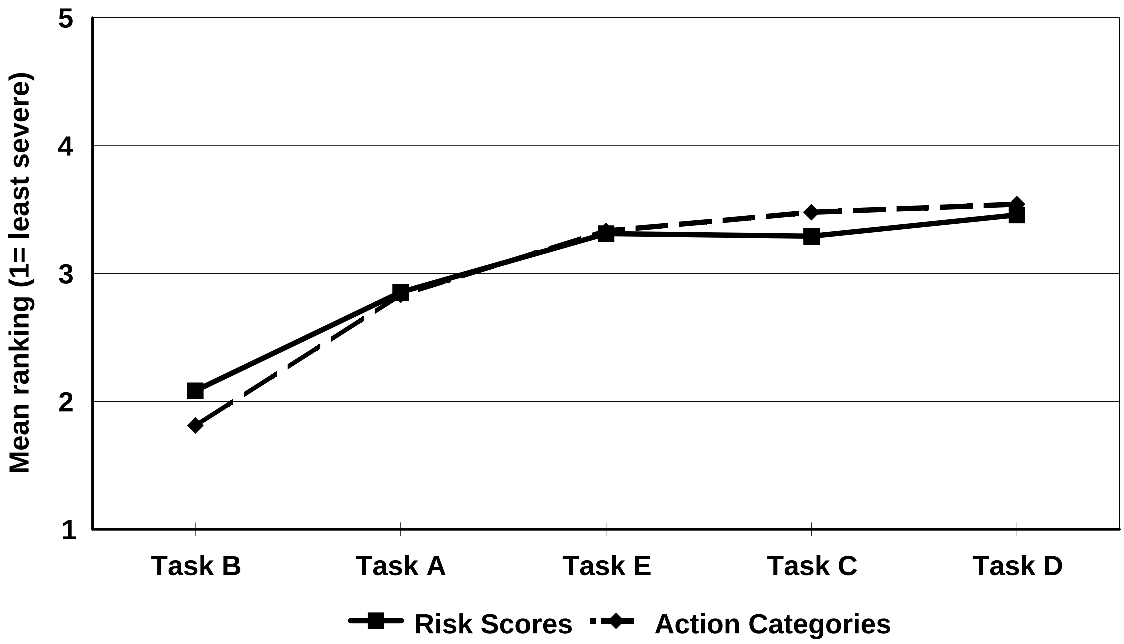

Figure 1 Mean ranking of the severity of the five tasks

In order to provide background information on the benchmarking exercise the severities of the five tasks were examined by comparing, across the tasks, the mean rankings of the risk scores and the Action Categories using the Friedman test. The results are shown graphically in Figure 1. For the comparison of the risk scores, χR^2 = 6.3 (N = 6, C = 5), P > 0.05. However, the conversion to Action Categories increased χR^2 to 9.067, P = 0.05 which is therefore on the border of significance. It appears from Figure 2 that this is due to Task B being ranked as the least severe task while the differences between the rankings of the other tasks are much smaller. The actual mean Action Categories for the five tasks are shown in Figure 2. The mean AC for Task B was 2.5 and the means for the other four tasks ranged between 3.0 and 3.3. Thus Task B was seen as being midway between needing action at some point and action soon and the other four tasks were seen as needing action more urgently than soon but not instantly.

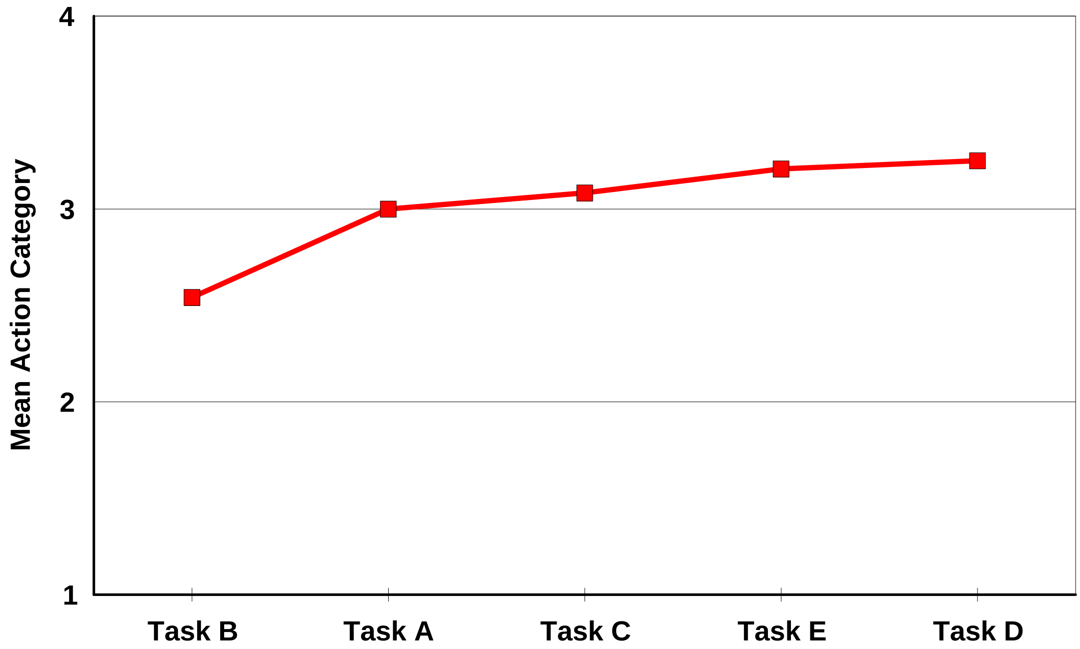

Figure 2 Mean Action Categories assigned to the five tasks

3.3.2 Assessment of raw risk scores

Figures 3 and 4 show how the different tools ranked the different tasks, averaged across the four experts. Figure 3 uses the QEC total and the REBA score whereas Figure 4 uses the QEC AL and the REBA AL.

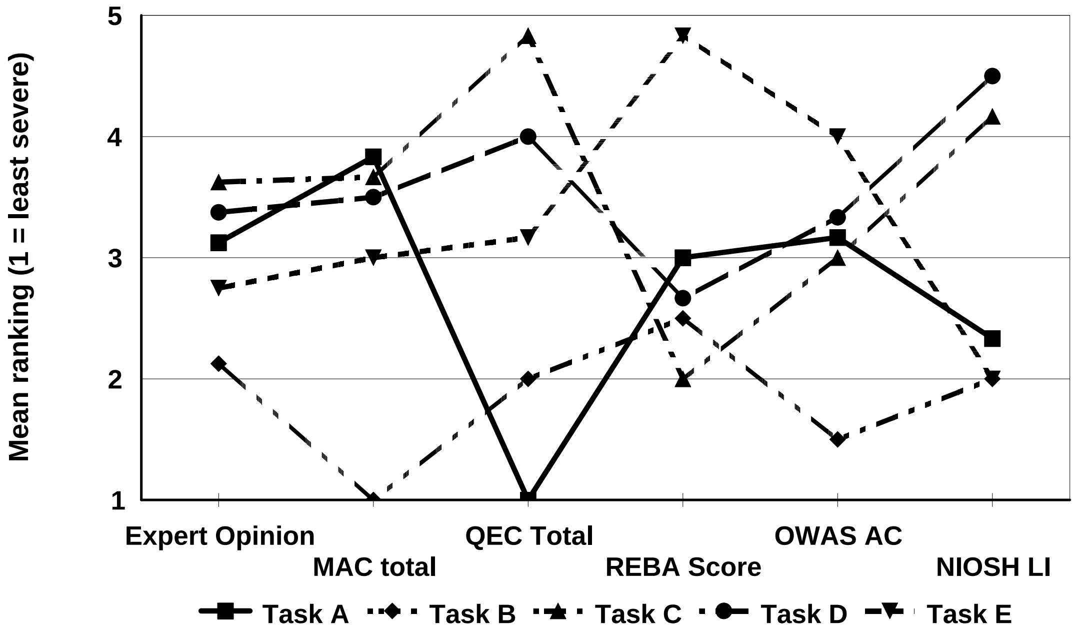

Figure 3 Ranking of risk scores (totals) of the different tools

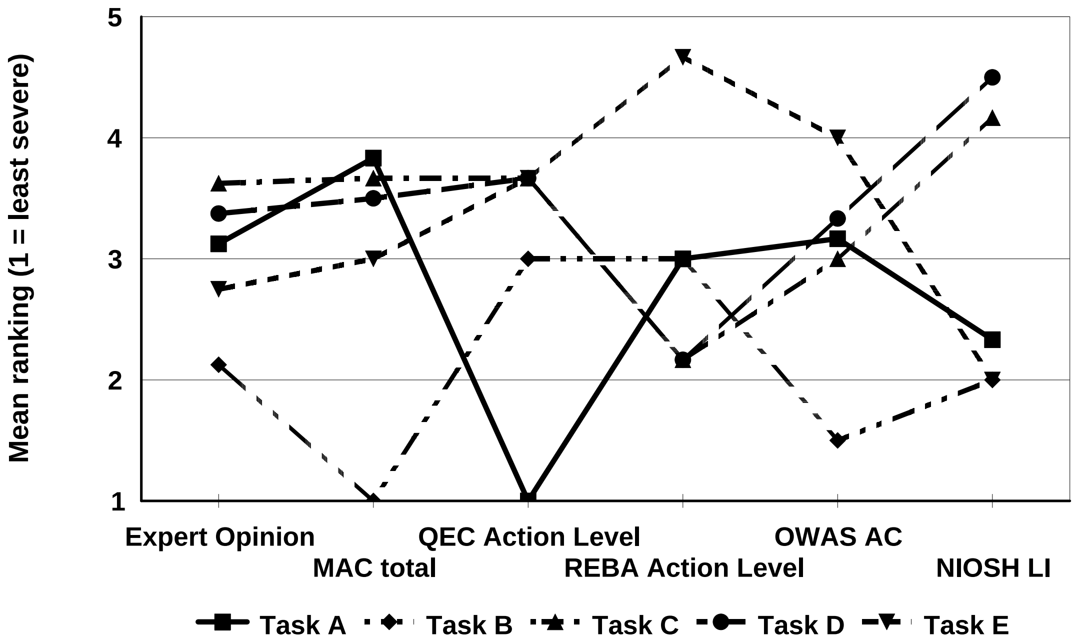

Figure 4 Ranking of risk scores (action levels) of the different tools

As can be seen, there are no systematic patterns in these charts. This random variation is reflected in the values of χR^2 of 8.4 and 5.4 respectively (both N = 6, C = 5), P > 0.05, obtained from the Friedman test. Therefore, the lack of significant differences between how the tools rank the severity of the tasks reflects the variation in the scoring systems of the different risk assessment tools used. It is also clear that the effect of converting the QEC total and the REBA score to their respective Action Levels is to reduce the ability of those tools to rank tasks since much of the variation between the scores given to the tasks has been removed. Therefore, the principle of using both scores should be adopted both to permit detailed ranking of the tasks while still providing an overall indication of the urgency of action.

3.3.3 Comparison of the different tools

Because the NIOSH LI values and the MAC scores were converted into Action Categories it became possible to compare all six assessment methods on the same four point ordinal scale. The mean of the Action Categories assigned by each tool after averaging across both the four experts and the five tasks are shown in Figure 5.

Analysis with the Friedman test gave a χR^2 value of 7.3 (N = 6, C = 5), P > 0.05 when the scores from each tool were ranked across the tasks. In other words, the tools did not produce significantly different Action Categories.

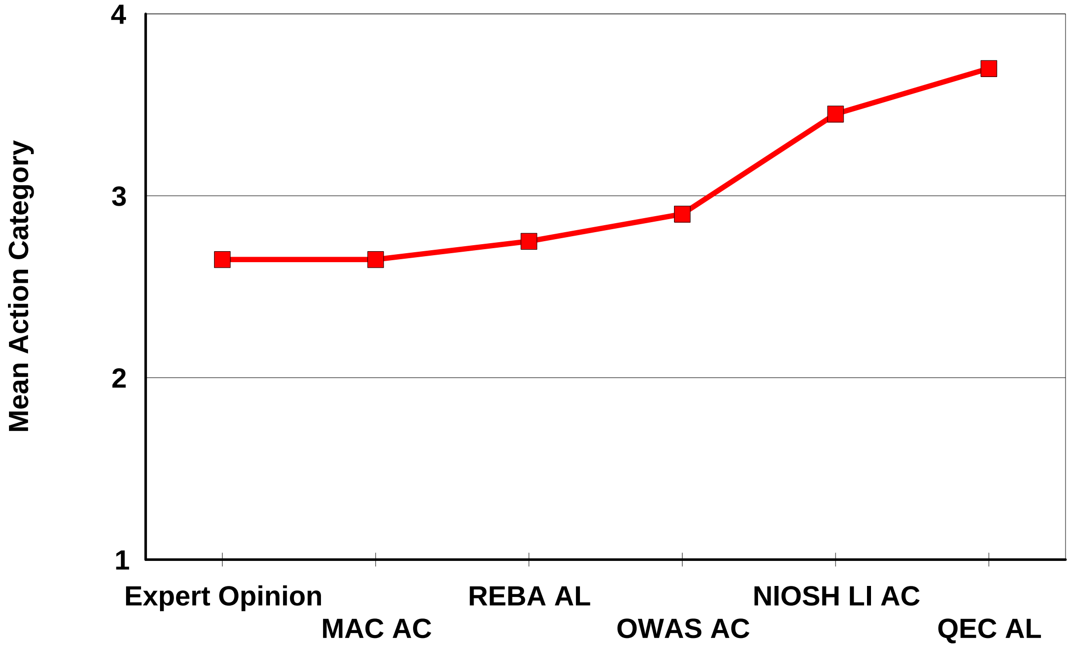

Figure 5 Mean Action Categories assigned by the different tools

Figure 6 shows how the different tools individually assigned Action Categories to the five tasks, averaged over the four experts. The Friedman test gave $\chi R^2 = 10.0$ (N = 5, C = 6), P > 0.05 when the scores from each task were ranked across the tools. This means that there were no statistically significant differences in the way that the different tools assigned Action Categories to the tasks.

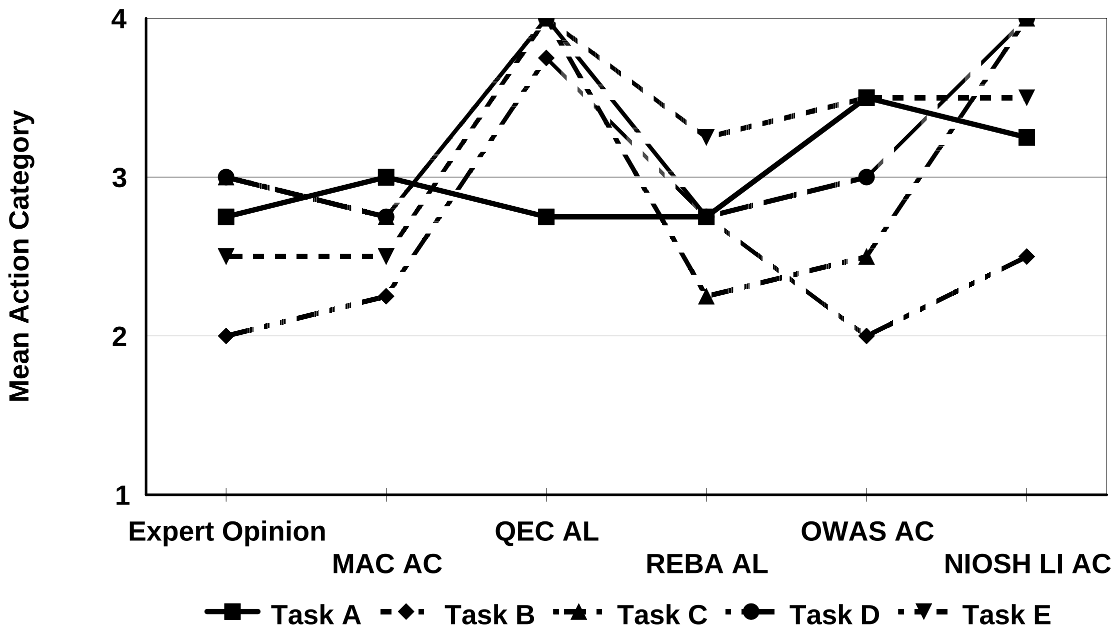

Figure 6 Action Categories assigned to the five tasks by the six tools

Effectively, therefore, the sequence of severity of tasks within each tool was random. The implication is that the tools are assessing risk in different ways and are therefore not directly comparable. In interpreting these results it must be recalled that arbitrary boundaries were chosen for the MAC and NIOSH LI Acs. It is possible that if different boundaries had been chosen that different results would have been obtained. However, because of the variation in the scores from the other tools this would be unlikely to have a major effect.

3.3.4 Ease of use of the tools

The Friedman test was used to compare the rankings of ease of use of the five tools (Figure 7). This gave $\chi R^2 = 11.2$, $p = 0.01$. In other words, the probability that the rankings of the five tools were all identical was only 1%. Since the Friedman test does not permit comparisons of pairs of scores, visual examination of the scores plotted in Figure 7 will indicate where the differences are likely to have arisen. It is apparent that OWAS and the MAC were the two easiest tools to use. The QEC and NIOSH equation were rated as the two most difficult to use.

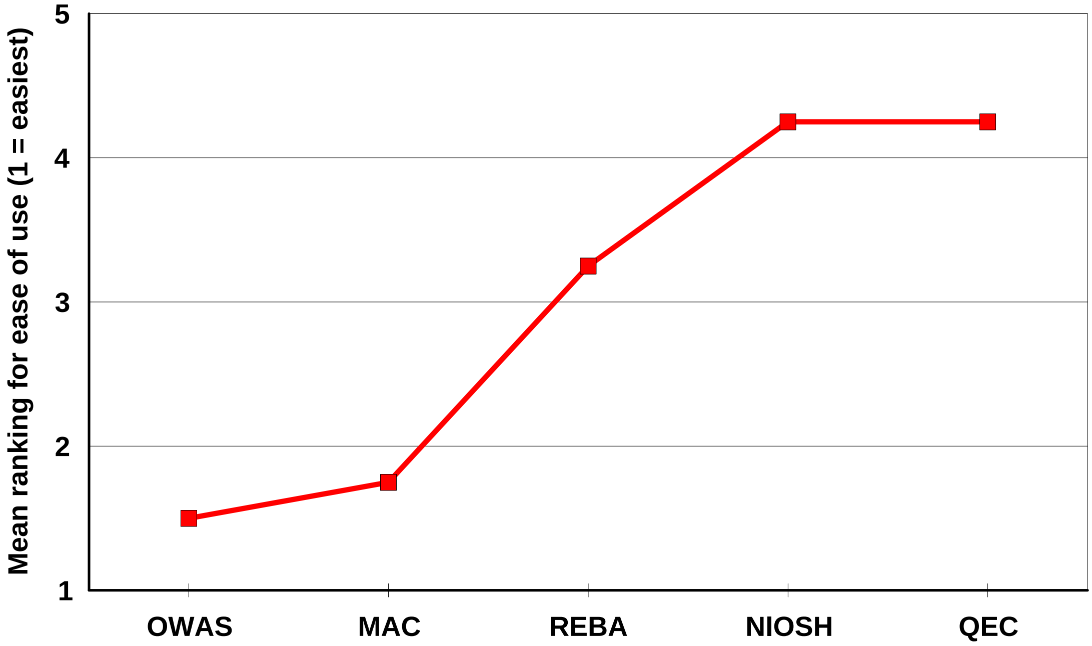

Figure 7 Mean rankings of ease of use of the different tools

3.3.5 Suitability of the tools

The Friedman test was used to compare the rankings of the suitability of the tools for assessing the risk of manual handling operations. This gave $\chi R^2 = 8.8$ ($N = 4$, $C = 5$, $P = 0.05$). Figure 8 shows that OWAS and REBA were perceived as the least suitable, and the MAC, NIOSH equation and QEC were seen as the more suitable.

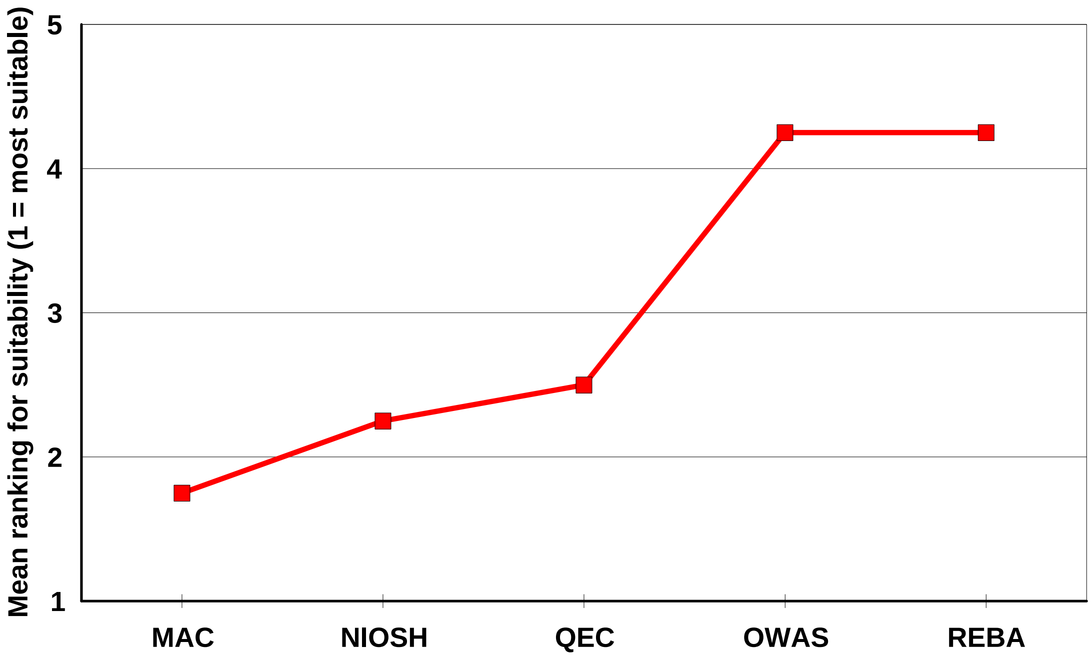

Figure 8 Mean rankings of suitability of the tools for assessing manual handling operations

Therefore, the MAC was seen as both one of the easiest tools to use and one of the most suitable. While the NIOSH Lifting Equation and the Quick Exposure Check were seen as equally suitable, they were seen as being the hardest tools to use. OWAS and REBA were seen as the least suitable tools despite OWAS being ranked as equally easy to use as the MAC, and REBA being ranked between the MAC and the NIOSH equation. While bias by the ergonomists involved in the trial cannot be ruled out, this does suggest that, unlike the other tools, the MAC has achieved the desirable aim of both good perceived ease of use and good perceived validity. OWAS, while very rapid in use, has a very limited classification of postures. REBA and the QEC have the difficulty of the need to look at multiple tables, particularly so with the QEC, which, in practice, does not seem "quick". NIOSH has the problem of needing accurate measurements of the parameters and involving a complex calculation which therefore needs time and care. The MAC has the advantage of only using three point scales and numerical scores that are easily added.

4 MODELS UNDERLYING MANUAL HANDLING RISK ASSESSMENT TOOLS

4.1 INTRODUCTION

Analysis was carried out of the scoring systems of the five tools to identify underlying assumptions and mathematical models.

4.2 THE HSE MANUAL HANDLING ASSESSMENT CHARTS (MAC)

Underlying the MAC is the assumption that the risk of MSDs from manual handling can be quantified using an additive model. In other words, a value representing risk due to hand distance from the load can be added to the risk from the weight and frequency of handling to give a combined risk score for the two risk factors. Clearly this can be extended for as many factors as are believed to be relevant and it is, of course, impossible to take into account all possible risk factors so there will always be risk that is unattributed as well as the inevitable error term in the model.

A mathematical representation is as follows:

(1) Risk score = True risk - Unattributed risk - Error

(2) Risk score = Load×frequency risk + hand distance risk + lift zone risk + trunk asymmetry risk + postural constraints risk + grip on load risk + floor surface risk + environmental factors risk

Symbolically, these equations can be written as:

(3) $R'_{TASK} = R_{TASK} - R_U - e$

(4) $R'_{TASK} = R_{LF} + R_H + R_{LZ} + R_A + R_P + R_G + R_F + R_E$

Therefore, the True Risk can be expressed as:

(5) $R_{TASK} = R'_{TASK} + R_U + e$

or

(6) $R_{TASK} = R_{LF} + R_H + R_{LZ} + R_A + R_P + R_G + R_F + R_E + R_U + e$

The units of risk are unspecified. Suitable units would be a measure of pain incidence, a measure of the rate that work days are lost, or a measure of the incidence of manual handling accidents. For the equation to be dimensionally correct, the units of each term must be the same.

It is also implicit that, apart from the load/frequency interaction, there are no interactions between risk factors. In other words, for example, there is assumed to be no interaction between the risk due to the horizontal reach and the risk due to trunk asymmetry. Therefore, while handling with a bent trunk due to a large reach and with a twisted trunk are both risk factors, the combination of bending and twisting while worse than bending or twisting on their own, does not increase the risk disproportionately.

The current system of scoring the MAC provides different weightings to the risk factors. Thus greater weight (6) is given to a Red load/frequency combination than to a Red lifting zone (3). While these weightings are based on expert judgement as to the relative risks of the different factors, they are as yet unvalidated against injury data. On the same basis, and as a result of a review of an earlier draft, no attempt has been made to link total scores to recommendations for remedial actions or enforcement action by HSE field professionals except for the purposes of the comparisons made in Section 3 of this report.

4.3 THE QUICK EXPOSURE CHECK (QEC)

The QEC is scored by assigning values to a number of 'Observer' and 'Worker' factors. For each of four body parts (back, shoulder, wrist, neck) several pairs of variables are fed into a lookup table to produce a series of sub-scores that are then totalled to produce a score for that body part. The factors and the ways that they 'interact' to provide the scores for the different body regions are listed in Table 6. The definitions of how the factors are scored are given in Tables 7 and 8. The lookup tables are given in Tables 9 to 13. The option exists within the scoring system to assess both manual handling and non-manual handling tasks which do not involve back movement. For the purpose of this work, only the manual handling task aspect was explored.

Table 6 Relationships between observer and worker factors in the QEC scoring system

	Worker factors	***Load***	***Duration***	***Hand force***
Observer factors		***a***	***b***	***c***
Back posture	***A***	Back exposure	Back exposure	
Back movement frequency	***B***	Back exposure	Back exposure	
Task height	***C***	Shoulder exposure	Shoulder exposure	
Arm movement frequency	***D***	Shoulder exposure	Shoulder exposure	
Wrist asymmetry	***E***		Wrist exposure	Wrist exposure
Wrist repetition	***F***		Wrist exposure	Wrist exposure
Neck asymmetry	***G***		Neck exposure	
Worker factors				
Duration	***b***	Back; shoulder exposure		Wrist exposure
Visual demand	***e***		Neck exposure	

Table 7 QEC Observer assessment

Factor	*Code*	*1*	*2*	*3*
Back posture	**A**	Almost neutral	Moderately flexed, twisted or side bent	Excessively flexed, twisted or side bent
Back movement frequency	**B**	≤ 3 per minute	About 8 per minute	≥ 12 per minute
(Non manual handling tasks)		B4: no static postures	B5: static postures	
Task height	**C**	At or below waist height	At about chest height	At or above shoulder height
Shoulder/arm motion	**D**	Some intermittent arm movement	Regular arm movement with some pauses	Almost continuous arm movement
Wrist/hand posture	**E**	Almost straight	Deviated or bent wrist posture	
Wrist/hand motion	**F**	≤ 10 per minute	11 - 20 per minute	> 20 per minute
Neck posture	**G**	Almost neutral	Occasional excessive bending/twisting of head/neck	Continuous excessive bending/twisting of head/neck

Table 8 QEC Worker assessments

	Code	*1*	*2*	*3*	*4*
Load	**a**	< 5 kg	6 - 10 kg	11 - 20 kg	> 20 kg
Duration	**b**	< 2 hours	2 - 4 hours	> 4 hours	
Hand force	**c**	< 1 kg	1 - 4 kg	> 4 kg	
Vibration	**d**	None/low	Medium	High	
Visual demand	**e**	No need to view fine details	Need to view some fine details		
Pace	**f**	Never difficult to keep up	Sometimes difficult to keep up	Often difficult to keep up	
Stress level	**g**	Not at all stressful	Low stress	Medium stress	High stress

Worker factors d, f and g (vibration, pace and stress level) are not linked to other factors in the scoring system but contribute to a subsidiary Worker Evaluation scale.

Li and Buckle (1999) stated that there, “is no evidence to confirm how the exposures to different risk factors should be weighted with respect to their contributions to WMSDs”. They also said that, “risk factors should be considered in combination with each other, and the effect of the combined risk factors … can be very different from the separate effects. … On the basis of this principle, the present score system has been formulated.”

Table 9 QEC Back Exposure Scores

	A1	*A2*	*A3*	*B1*	*B2*	*B3*	*B4*	*B5*	*b1*	*b2*	*b3*
a1	2	4	6	2	4	6	-	-	2	4	6
a2	4	6	8	4	6	8	-	-	4	6	8
a3	6	8	10	6	8	10	-	-	6	8	10
a4	8	10	12	8	10	12	-	-	8	10	12
b1	2	4	6	2	4	6	2	4	-	-	-
b2	4	6	8	4	6	8	4	6	-	-	-
b3	6	8	10	6	8	10	6	8	-	-	-

Table 10 QEC Shoulder/Arm Exposure Scores

	C1	*C2*	*C3*	*D1*	*D2*	*D3*	*b1*	*b2*	*b3*
a1	2	4	6	2	4	6	2	4	6
a2	4	6	8	4	6	8	4	6	8
a3	6	8	10	6	8	10	6	8	10
a4	8	10	12	8	10	12	8	10	12
b1	2	4	6	2	4	6	-	-	-
b2	4	6	8	4	6	8	-	-	-
b3	6	8	10	6	8	10	-	-	-

Table 11 QEC Wrist/Hand Exposure Scores

	F1	*F2*	*F3*	*E1*	*E2*	*b1*	*b2*	*b3*
c1	2	4	6	2	4	2	4	6
c2	4	6	8	4	6	4	6	8
c3	6	8	10	6	8	6	8	10
b1	2	4	6	2	4	-	-	-
b2	4	6	8	4	6	-	-	-
b3	6	8	10	6	8	-	-	-

Table 12 QEC Neck Exposure Scores

	G1	*G2*	*G3*	*e1*	*e2*
b1	2	4	6	2	4
b2	4	6	8	4	6
b3	6	8	10	6	8

Table 13 QEC Worker's Evaluations Scores

d1	*d2*	*d3*	*f1*	*f2*	*f3*	*g1*	*g2*	*g3*	*g4*
1	4	9	1	4	9	1	4	9	16

In the QEC the scores for different body regions are summed to provide the total exposure score. Thus:

(7) Total exposure score = Total back score + Total shoulder/arm score + Total wrist/hand score + Total neck score

Though they are not explicitly stated by the authors (Li and Buckle, 1999), the following models underlie the scoring system in the lookup tables (Tables 9 to 12):

(8) Total back score = 4A + 4B + 6a + 6b - 10

(9) Total shoulder/arm score = 4C + 4D + 6a + 6b - 10

(10) Total wrist/hand score = 4E + 4F + 6b + 6c - 10

(11) Total neck score = 2G + 4b + 2e - 4

Hence:

(12) Total exposure score = 4A + 4B + 4C + 4D + 4E + 4F + 2G + 12a + 22b + 6c + 2e - 34

All of the factors have minimum scores of 1. Maximum scores range from 2 to 4. The scores that can be obtained from Equations (8) to (12) are given in Table 14.

Table 14 QEC minimum and maximum exposure scores

Exposure score	*Minimum*	*Maximum*	*Range*
Total back score	10	56	47
Total shoulder/arm score	10	56	47
Total wrist/hand score	10	46	37
Total neck score	2	18	17
Total exposure score	32	176	144

The authors have also published on the Internet some suggested ‘QEC Action Levels’ at www.geocities.com/qecuk/QECActionlevels. These are described as being “based on the assessment of a variety of tasks using both the QEC and RULA, and comparing the exposure scores obtained from both tools”. The relevant figures for manual handling tasks are set out in Table 15.

Table 15 QEC Action Levels for manual handling tasks

Action Level	*Percentage score*	*Action suggested*	*Equivalent RULA score*	*Total exposure score*
1	0-40%	Acceptable	1-2	32-70
2	41-50%	Investigate further	3-4	71-88
3	51-70%	Investigate further and change soon	5-6	89-123
4	71-100%	Investigate and change immediately	7	124-176

The implications of this model, particularly Equation (12), are that:

- The most crucial factor in the model is duration (b) which contributes to all four sub-scores. A score of 1 is given for a task with a duration of less than 2 hours. The score is 2 for a task lasting between 2-4 hours and 3 for a task lasting more than 4 hours. Thus if the duration of an otherwise ideal task is increased from 2 to 4 hours then the total score increases from 32 to 54. If it increases to more than 4 hours, the total increases to 74, forcing it into Action Level 2.

- The second most important factor is the load (a) which contributes to both the back and shoulder/arm score.

- The third most important factor is the hand force (c).

- The 'observer factors': back posture (A), back movement frequency (B), task height (C), arm movement frequency (D), wrist asymmetry (E) and wrist repetition (F) all have equal weightings, except that neck asymmetry (G) has a lower weighting.

- There are no interactions in this model, even though the authors were seeking to create a model that took into account the effects of combining risk factors. Even though the scores are read from two-way tables, the score due to one factor does not vary with the score due to another factor. In other words the model is purely additive, and no factors are multiplied by other factors.

- The nature of the model restricts the values that can be obtained from it. In particular, all the scores could be divided by two without affecting the model. Also, the minimum total score that can be obtained is 32 so the total range of scores is 144.

- The mapping of the total scores onto Action Levels is non-linear and therefore ordinal.

4.4 REBA

The scoring system of REBA is based on that of RULA (McAtamney and Corlett, 1993). It provides a series of lookup tables to allow the assessment of postures of different body regions and of force/activity requirements. "Change scores" are provided for each body part to modify the basic score if additional postural risk factors (usually in a different anatomical plane) are present for a particular body segment. Tables 16 to 18 and 20 to 22 define how REBA scores the postures of body parts and Tables 19, 23, and 24 define how the other factors are scored.

Table 8 REBA neck scoring

Movement	*Score*	*Change score*
0° - 20° flexion	1	+ 1 if twisting or side flexed
> 20° flexion or in extension	2	

Table 9 REBA trunk scoring

Movement	*Score*	*Change score*
Upright	1	+ 1 if twisting or side flexed
0° - 20° flexion; 0° - 20° extension	2	
20° - 60° flexion; > 20° extension	3	
> 60° flexion	4	

Table 10 REBA legs scoring

Position	*Score*	*Change score*
Bilateral weight bearing, walking or sitting	1	+ 1 if knees between 30° and 60° flexion
Unilateral weight bearing; Feather weight bearing or an unstable posture	2	+ 2 if knees are > 60° flexion (N.B., Not for sitting)

Table 11 REBA load/force scoring

Load	*Score*	*Change score*
< 5 kg	0	+1 if shock or rapid build up of force occurs
5 - 10 kg	1	
> 10 kg	2	

Table 12 REBA upper arms scoring

Position	*Score*	*Change score*
20° extension to 20° flexion	1	+ 1 if arm is abducted and/or rotated + 1 if shoulder is raised - 1 if leaning, supporting weight of arm or if posture is gravity assisted
> 20° extension; 20° - 45° flexion	2	
45° - 90° flexion	3	
> 90° flexion	4	

Table 13 REBA lower arms scoring

Movement	*Score*
60° - 100° flexion	1
< 60° flexion or > 100° flexion	2

Table 14 REBA wrists scoring

Movement	*Score*	*Change score*
0° - 15° flexion/extension	1	+ 1 if wrist is deviated or twisted
> 15° flexion/extension	2	

Table 15 REBA coupling scoring

Coupling	*Score*	*Description*
Good	0	Well-fitting handle and a mid-range power grasp
Fair	1	Hand hold acceptable but not ideal or coupling is acceptable via another part of the body
Poor	2	Hand hold not acceptable although possible
Unacceptable	3	Awkward, unsafe grip, no handles. Coupling is unacceptable using other parts of the body

Table 21 REBA activity score

Activity	*Score*	*Description*
Static posture	+ 1	1 or more body parts are static, e.g., held for longer than 1 min
Repetition	+ 1	Repeated small range actions, e.g., repeated more than 4 times per minute (not including walking)
Instability	+ 1	Action causes rapid large range changes in postures or an unstable base

Complex lookup tables (Tables 26 to 29) are used to combine the scores from the body parts and the other factors. This finally produces a "REBA score" ranging between 1 and 15 which is converted to an "Action Level" (Table 30) linked to a suggested urgency of action. The urgency of action scale is derived from RULA and hence from OWAS. There are not precise mathematical relationships underlying these tables. However, it has proved possible to generate approximate models which are listed in Equations (13) to (28). Errors in these models are shown in Tables 26 to 29 using the hatching in Table 25.

Table 22 Hatching code for model errors

-4	-3	-2	-1	0	1	2	3	4

Table A in REBA combines the scores for the neck, trunk and legs (Table 26). With a minimum error of 0 and a maximum error of 1, it can be derived using Equation (13):

(13) Table A score $\approx$ Neck + Trunk + Legs -2

The Load/Force score is added to the Table A score to generate Score A:

(14) Score A = Table A score + Load/Force

Therefore:

(15) Score A $\approx$ Neck + Trunk + Legs + Load/Force - 2

Table 23 REBA Table A - Combined neck, trunk and legs score

Neck score	*Trunk score*	*Legs = 1*	*Legs = 2*	*Legs = 3*	*Legs = 4*
1	***1***	1	2	3	4
1	***2***	2	3	4	5
1	***3***	2	4	5	6
1	***4***	3	5	6	7
1	***5***	4	6	7	8
2	***1***	1	2	3	4
2	***2***	3	4	5	6
2	***3***	4	5	6	7
2	***4***	5	6	7	8
2	***5***	6	7	8	9
3	***1***	3	3	5	6
3	***2***	4	5	6	7
3	***3***	5	6	7	8
3	***4***	6	7	8	9
3	***5***	7	8	9	9

REBA Table B similarly combines the scores for the Upper arm, lower arm and wrist (Table 27). A maximum error of ±1 is produced by using Equation (16):

(16) Table B score $\approx$ Upper arm + Lower arm + Wrist - 2

Table 24 REBA Table B - combined score for upper arm, lower arm and wrist

Upper arm score	*Lower arm score*	*Wrist score = 1*	*Wrist score = 2*	*Wrist score = 3*
1	***1***	1	2	3
1	***2***	1	2	3
2	***1***	3	4	5
2	***2***	2	3	4
3	***1***	3	4	5
3	***2***	4	5	5
4	***1***	4	5	5
4	***2***	5	6	7
5	***1***	6	7	8
5	***2***	7	8	8
6	***1***	7	8	8
6	***2***	8	9	9

A Coupling score is added to the Table B score to generate Score B:

(17) Score B = Table B score + Coupling

Therefore:

(18) Score B ≈ Upper arm + Lower arm + Wrist + Coupling - 2

Score A and Score B are combined using 'Table C'. One model (Equation 19) that can be constructed for this process has a maximum error of +4 and a minimum error of -3, with a mean error of 0.028 (SD 1.36). A total of 38/144 (26.4%) predictions are exact, with 104 (72.2%) being within ±1 (Table 28).

(19) Score C ≈ INT(2 + (Score A + Score B)/2)

Table 25 Table C - combination of Score A and Score B (errors for Model 1)

Score B ***Score A***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Another model (Equation 20) has a maximum error of +3, and a minimum error of -4, with a mean (SD) of -0.056 (1.22). 54/144 (37.5%) predictions are exact with 62 (43.1%) being ±1 out, giving 116/144 (80.6%) within ±1. While the mean error is slightly larger, the smaller SD results in more predictions being exact (Table 29).

(20) Score C ≈ Score A + INT(Score B/3)

It is not clear whether the authors set out to create a scoring system based round these models or merely sought to create ordinal scoring systems with the desired ranges. If it is the first of these, it appears that adjustments were deliberately made in individual cells, but reasons for doing so are not stated. If it is the second, then it appears that a level of arbitrariness occurred in the allocation of scores to cells, particularly in Table C. The Table C score is, with only six exceptions, never less than the Score A value. This has the effect that when Score A = 12, variation in Score B has no effect since the Table C Score always equals 12. The same effect is not obtained with Score B since the Table C score is less than Score B in 41/144 cases. The second Score C model (Equation 20) reflects these features.

Table 26 Table C - combination of Score A and Score B (errors for Model 2)

Score B / *Score A*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Substituting for Score A and Score B in Equation (19) gives:

(21) Score C ≈ INT ((Neck + Trunk + Legs + Load/Force + Upper arm + Lower arm + Wrist + Coupling) / 2)

And in Equation (20)

(22) Score C ≈ Neck + Trunk + Legs + Load/Force - 2 + INT ((Upper arm + Lower arm + Wrist + Coupling - 2) / 3)

The initial REBA score is obtained by adding an “Activity” score to Score C, i.e.:

(23) REBA Score = Score C + Activity Score

Expansion of Equation (23) using the models in Equations (21) and (22) gives:

(24) REBA Score ≈ INT ((Neck + Trunk + Legs + Load/Force + Upper arm + Lower arm + Wrist + Coupling) / 2) + Activity score

or

(25) REBA Score ≈ Neck + Trunk + Legs + Load/Force - 2 + INT ((Upper arm + Lower arm + Wrist + Coupling - 2) / 3) + Activity score

Table 27   REBA Action levels

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

The mapping of REBA scores onto Action Levels in Table 30 also appears to be based round an ordinal relationship rather than a mathematically defined one. The best equation that can be fitted to the relationship is correct for 13 of the 15 REBA Scores, having an error of 1 for REBA Scores of 1 and 11:

(26) REBA Action Level ≈ INT (REBA Score/4 + 1)

Therefore, in terms of the two models in Equations (24) and (25):

(27) REBA Action Level ≈ INT(INT((Neck + Trunk + Legs + Load/Force
+ Upper arm + Lower arm + Wrist + Coupling) / 2)
+ Activity Score) / 4 + 1)

or

(28) REBA Action Level ≈ INT((Neck + Trunk + Legs + Load/Force - 2
+ INT ((Upper arm + Lower arm + Wrist + Coupling - 2) / 3)
+ Activity Level) / 4 + 1)

The problem with Equation (26) is that one of the errors is crucial in that a REBA Score of 1 is converted to an Action Level of 1 when it should be zero, and there is no other REBA Score that equates to an Action Level of Zero.

It must be remembered that no evidence is yet available to validate the REBA scoring system nor the allocation of recommendations for action to particular REBA scores/Action levels and the authors stress the need for further validation of the tool. Therefore, it is necessary to treat such scoring systems as no more than ordinal scales designed to rank tasks by severity and provide a preliminary guide to the level of remedial action needed.

4.5 OWAS

OWAS does not have any kind of underlying mathematical model. Instead it relies on a lookup table that converts four digit posture codes into Action Categories. Table 31 gives the OWAS codes for individual body segments. The overall posture code is formed by putting the codes for the four segments in the sequence of Back, Arms, Legs and Load. Table 32 list the definitions of the Action Categories. Table 33 converts the posture codes into Action Categories.

Table 16 OWAS posture/load codes

Back		*Arms*		*Legs*		*Load*	
Straight	1	2 below shoulder height	1	Sitting	1	< 10 kg	1
Bent	2	1 above shoulder height	2	Standing on two straight legs	2	10 - 20 kg	2
Twisted	3	2 above shoulder height	3	Standing on one straight leg	3	> 20 kg	3
Bent and Twisted	4			Standing on two bent legs	4		
				Standing on one bent leg	5		
				Kneeling	6		
				Walking	7		

Table 17 OWAS Action Categories

Action Category	*Action required*
AC 1	No action required
AC 2	Action required in the near future
AC 3	Action required as soon as possible
AC 4	Action required immediately

4.6 THE 1991 NIOSH REVISED LIFTING EQUATION

This is a multiplicative model that calculates a Recommended Weight Limit (RWL) for a particular lifting task from the physical parameters of the job. It takes the form:

(7) $$RWL = LC \times HM \times VM \times DM \times FM \times AM \times CM$$

where HM, VM, DM, FM, AM and CM are the Horizontal distance Multiplier, the Vertical location Multiplier, the vertical Distance Multiplier, the Frequency Multiplier, the Asymmetry Multiplier, and the Coupling Multiplier respectively. The method is to start from a fixed maximum value, the Load Constant, (LC) of 23 kg, and reduce it with the multipliers which are all less than or equal to 1.0. The multipliers are defined as being equal to 1.0 under ideal lifting conditions where the horizontal distance = 250 mm, the vertical position = 750 mm, the vertical distance of lift $\leqslant$ 250 mm, the frequency of lift = 0.2 lifts per minute, the duration $\leqslant$ 1 hour, the task asymmetry = 0°, and the hand/object coupling = Good.

Since both the RWL and the LC have dimensions of Mass, all of the multipliers must be dimensionless. The precise forms of the equations used to convert the task parameters into the multipliers are not relevant to this benchmarking exercise but are given by Waters *et al.* (1994).

Table 18 OWAS codes and Action Categories

OWAS code	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**	**OWAS code**	**AC**
1111	1	1251	2	2111	2	2251	3	3111	1	3251	4	4111	2	4251	4
1112	1	1252	2	2112	2	2252	4	3112	1	3252	4	4112	3	4252	4
1113	1	1253	2	2113	3	2253	4	3113	1	3253	4	4113	3	4253	4
1121	1	1261	1	2121	2	2261	3	3121	1	3261	3	4121	2	4261	4
1122	1	1262	1	2122	2	2262	3	3122	1	3262	3	4122	2	4262	4
1123	1	1263	1	2123	3	2263	4	3123	1	3263	3	4123	3	4263	4
1131	1	1271	1	2131	2	2271	2	3131	1	3271	1	4131	2	4271	2
1132	1	1272	1	2132	2	2272	3	3132	1	3272	1	4132	2	4272	3
1133	1	1273	1	2133	3	2273	4	3133	2	3273	1	4133	3	4273	4
1141	2	1311	1	2141	3	2311	3	3141	3	3311	2	4141	4	4311	4
1142	2	1312	1	2142	3	2312	3	3142	3	3312	2	4142	4	4312	4
1143	2	1313	1	2143	3	2313	4	3143	3	3313	3	4143	4	4313	4
1151	2	1321	1	2151	3	2321	2	3151	4	3321	1	4151	4	4321	2
1152	2	1322	1	2152	3	2322	2	3152	4	3322	1	4152	4	4322	3
1153	2	1323	1	2153	3	2323	3	3153	4	3323	1	4153	4	4323	4
1161	1	1331	1	2161	2	2331	3	3161	1	3331	2	4161	4	4331	3
1162	1	1332	1	2162	2	2332	3	3162	1	3332	3	4162	4	4332	3
1163	1	1333	1	2163	2	2333	3	3163	1	3333	3	4163	4	4333	4
1171	1	1341	2	2171	2	2341	3	3171	1	3341	4	4171	2	4341	4
1172	1	1342	2	2172	3	2342	4	3172	1	3342	4	4172	3	4342	4
1173	1	1343	3	2173	3	2343	4	3173	1	3343	4	4173	4	4343	4
1211	1	1351	2	2211	2	2351	4	3211	2	3351	4	4211	3	4351	4
1212	1	1352	2	2212	2	2352	4	3212	2	3352	4	4212	3	4352	4
1213	1	1353	3	2213	3	2353	4	3213	3	3353	4	4213	4	4353	4
1221	1	1361	1	2221	2	2361	4	3221	1	3361	4	4221	2	4361	4
1222	1	1362	1	2222	2	2362	4	3222	1	3362	4	4222	3	4362	4
1223	1	1363	1	2223	3	2363	4	3223	1	3363	4	4223	4	4363	4
1231	1	1371	1	2231	2	2371	2	3231	1	3371	1	4231	3	4371	2
1232	1	1372	1	2232	3	2372	3	3232	1	3372	1	4232	3	4372	3
1233	1	1373	2	2233	3	2373	4	3233	2	3373	1	4233	4	4373	4
1241	2			2241	3			3241	4			4241	4		
1242	2			2242	4			3242	4			4242	4		
1243	2			2243	4			3243	4			4243	4		

Risk is expressed by the Lifting Index (LI), which is the load divided by the RWL.

(8) LI = Load / RWL

Since both Load and RWL have dimensions of Mass, the LI also must be dimensionless.

The limited evidence available to date suggests that risk is probably not a linear function of LI (Dempsey *et al.*, 2002). However, should it be proved that risk is, in fact, linearly related to load, then the LI would be a ratio of risk, or a risk relative to lifting the RWL, so that:

(9) Relative Risk = Risk of handling Load / Risk of handling RWL

However, the level of risk that the RWL represents is simply unknown (Leamon, 1994), and it is not even known whether it represents a constant level of risk taking into account the different parameters in it.

It also follows from the definition of the RWL that:

(10) LI = Load / (LC × HM × VM × DM × FM × AM × CM)

i.e.,

(11) LI = Load / LC × 1 / (HM × VM × DM × FM × AM × CM)

The risk is from handling loads that have mass, not from dimensionless multipliers, which merely modify the risk as the parameters of the task change from ideal conditions. Therefore, the Relative Risk (RR) can be expressed as:

(12) RR = Risk of handling load / (Risk of handling LC × HM × VM × DM × FM × AM × CM)

(13) RR = Risk of handling load / Risk of handling LC × 1 / (HM × VM × DM × FM × AM × CM)

Therefore, an implicit assumption of the NIOSH equation is that the absolute risk of handling a load could be established by determining the proportions of the population who would be injured by handling the Load Constant of 23 kg and the actual load under ideal conditions.

Mathematically a multiplicative equation such as the NIOSH equation can be converted to an additive model by taking logarithms. Equation (30) therefore becomes:

(14) Log LI = log load - log RWL

In fact, what is obtained is a subtractive model that can be expanded to:

(15) Log LI = log load - log LC - log HM - log VM - log DM - log FM - log AM - log CM

Expressing this in terms of risk, as in Equation (35), and where RL = Risk of handling a load and RLC = Risk of handling the Load Constant:

(16) Log (RR) = Log (RL) - Log (RLC) - log HM - log VM - log DM - log FM - log AM - log CM

However, because each multiplier is $\leqslant$ 1.0 the log of it will be either zero (multiplier = 1.0) or negative (multiplier < 1.0). This means that an additive model, using functions of the underlying variables (H, V, D, F, A, C) rather than the multipliers, is:

(17) Log (RR) = Log (Risk of handling load) - Log (Risk of handling LC) + f(H) + f(V) + f(D) + f(F) + f(A) + f(C)

Manipulating Equation (39) gives the following expression for absolute risk of handling a load:

(18) Log (RL) = Log (RR) + Log (Risk of handling LC) + log HM + log VM + log DM + log FM + log AM + log CM

Comparing this with Equation (6), the model underlying the MAC, shows that fundamentally different approaches have been taken because the NIOSH equation uses risk relative to handling the Load Constant under ideal conditions which is then adjusted using the task parameters whereas the MAC attempts to estimate absolute risk from the parameters of the task.

4.7 COMPARISON OF SCORING SYSTEMS USED BY THE DIFFERENT RISK ASSESSMENT TOOLS

4.7.1 Load and frequency of handling

Table 19 Load scoring at 1 lift every minute

		Category 1	*Category 2*	*Category 3*	*Category 4*
MAC lifting flowchart	***Load***	0 - 14 kg	14 - 30 kg	30 - 44 kg	> 44 kg
	Colour	Green	Amber	Red	Purple
	Score	0	4	6	10
QEC	***Load***	0 - 5 kg	6 - 10 kg	11 - 20 kg	> 20 kg
	Description	Light	Moderate	Heavy	Very heavy
	Score	1	2	3	4
REBA	***Load***	0 - 5 kg	5 - 10 kg; 0 - 5 kg with impulse	> 10 kg; 5 - 10 kg with impulse	> 10 kg with impulse
	Score	0	1	2	3
OWAS	***Load***	< 10 kg	10 - 20 kg	> 20 kg	
	Score	1	2	3	
	AC distribution	AC1 25; AC2 28; AC3 13; AC4 18	AC1 25; AC2 17; AC3 21; AC4 21	AC1 22; AC2 8; AC3 21; AC4 33	
NIOSH	***Load***	0 - 21.6 kg	21.6 - 43.2 kg	43.2 - 64.9 kg	> 65 kg
	Score	LI $\leqslant$ 1	1 < LI $\leqslant$ 2	2 < LI $\leqslant$ 3	LI > 3

Table 34 compares the way the tools score the load at a frequency of one lift every minute. Since QEC, REBA and OWAS do not adjust their scores to take account of frequency, Table 35 compares only the MAC and the NIOSH equation at a frequency of one lift every 30 minutes. Calculations of the NIOSH Lifting Index are based on the assumption that the multipliers other than frequency are equal to 1.0 and therefore do not affect the RWL. The loads given are calculated from the boundaries of the stated LI categories.

Whereas the other tools increase the score monotonically as the load increases, this is not true of OWAS Action Categories (AC). Any load can fall into any AC, depending on the other factors assessed by OWAS. Therefore, in Table 34, each load category is classified by the number of postures that fall into each AC. For each level of load, 84 OWAS scores are defined by the other three variables. As the load increases there is a general tendency to increase the number of postures in the higher ACs and therefore increase the urgency of remedial action. This is done particularly by reducing the number in AC2.

The coding ranges for the load/force vary widely. Thus, REBA classifies any load over 10 kg in the highest load category. This is despite it being aimed at health care/patient handling tasks where the loads are almost inevitably many times this figure. The QEC classifies loads over 20 kg as "Very heavy". The MAC tends to follow the NIOSH equation in accepting much greater loads. For the infrequent lifts (once every 30 minutes), 18 kg is considered acceptable. For the QEC this is "Heavy"; for REBA this is in the highest category; for OWAS this is in the second category; and for NIOSH, assuming all other factors are ideal, the LI is less than 1.0.

Table 20 Load scoring at 1 lift every 30 minutes

		Category 1	*Category 2*	*Category 3*	*Category 4*
MAC lifting flowchart	***Load***	0 - 18 kg	18 - 39 kg	39 - 50 kg	> 50 kg
	Colour	Green	Amber	Red	Purple
	Score	0	4	6	10
NIOSH	***Load***	0 - 23 kg	23 - 46 kg	46 - 69 kg	> 69 kg
	Score	LI ⩽ 1	1 < LI ⩽ 2	2 < LI ⩽ 3	LI > 3

4.7.2 Horizontal distance of the load

Table 36 compares the ways the different tools assess the lever arm that the load exerts about the low back of the handler. All except the NIOSH equation do this by assessing the posture of the trunk. The MAC also utilises the posture of the upper arms in the assessment. The NIOSH equation uses the horizontal distance from the hands to the point mid way between the ankles as a surrogate for the distance between the hands and the low back.

The MAC and OWAS descriptions are purely qualitative. REBA relies on estimates of trunk angle, but the first two categories overlap, leading to confusion in coding. Also, the intervals are not equal, making the scoring ordinal. The QEC combines qualitative descriptions with numerical estimates of trunk angle, using the same intervals as categories 2 to 4 of REBA. The reliance of the NIOSH equation on measurements of hand distance from the mid ankle position and the way that this value is divided into a reference distance makes it very sensitive to measurement error, especially since the horizontal multiplier is the most important multiplier in the equation. OWAS does not define the boundary between a straight trunk and a "bent" trunk, but where trunk bending occurs the Action Category is never 1.

The LI values for the NIOSH equation are calculated for the nearest and farthest values of the range that the equation specifies for the horizontal distance, and also for two intermediate values. The load was assumed to be equal to the Load Constant and all of the other multipliers were assumed to be equal to 1.0 and therefore to not affect the RWL and LI.

Table 21 Hand distance/back flexion scoring

		Category 1	*Category 2*	*Category 3*	*Category 4*
MAC lifting flowchart	***Description***	Close - upper arm vertical and/or trunk upright	Moderate - upper arm angled or trunk bent forward	Far - upper arm angled and trunk bent forward	
	Colour	Green	Amber	Red	
	Score	0	3	6	
QEC	***Description***	Almost neutral back	Moderately flexed back	Excessively flexed back	
	Angle	0° - 20°	20° - 60°	> 60°	
	Score	1	2	3	
REBA	***Load***	Upright trunk	0° - 20° trunk flexion	20°- 60° trunk flexion	> 60° trunk flexion
	Score	1	2	3	4
OWAS	***Load***	Straight trunk	Bent trunk	Trunk bent and twisted	
	Score	1	2	4	
	AC distribution	AC1 44; AC2 17; AC3 2; AC4 0	AC1 0; AC2 19; AC3 28; AC4 16	AC1 0; AC2 10; AC3 15; AC4 38	
NIOSH	***Load***	Hands 250 mm from mid ankle	Hands 375 mm from mid ankle	Hands 500 mm from mid ankle	Hands 625 mm from mid ankle
	Score	LI = 1	LI = 1.5	LI = 2	LI = 2.5

4.7.3 Height/distance of handling

Table 37 compares the methods of assessing a complex of factors related to the vertical location of the load and the vertical distance it travels through during the lift. The different assessment methods use very different approaches to assessment of these factors. NIOSH carefully distinguishes between the vertical height of the hands and the vertical lift distance whereas REBA does not assess either factor at all, only assessing trunk and arm posture.

The zones in the MAC relate to the need for stooping and reaching upwards so the ideal zone is specified as being between knee and elbow height. In the QEC, by contrast, a different model of risk, based on shoulder posture, has been used which largely matches patterns of lifting strength so that the strongest region below waist height is least hazardous. The QEC does not increase the risk assigned when the lift occurs from below knee height in the way that the MAC does. Like the QEC, OWAS takes the approach of comparing the hand position with shoulder height, therefore assigning increased risk when handling occurs above the shoulders.

NIOSH works around an “ideal” lifting height of 750 mm, which is approximately knuckle height. The RWL decreases as the absolute distance away from the 750 mm height increases and as the distance lifted through increases. The LI has been calculated for the vertical position using the “ideal” lifting height and for both the minimum or maximum heights specified. For the distance multiplier, LI values were calculated for the minimum or maximum distances of lift. In both cases all other multipliers were set to 1.0 and the load set to 23 kg.

Table 22 Hand height/vertical distance scoring

		Category 1	*Category 2*	*Category 3*
MAC lifting flowchart	***Description***	Lift from above knee and/or below elbow height	Lift from below knee and/or above elbow height	Lift from floor level or below and/or above head height
	Colour	Green	Amber	Red
	Score	0	3	6
QEC	***Description***	Task performed at or below waist height	Task performed at about chest height	Task performed at or above shoulder height
	Score	1	2	3
OWAS	***Description***	Two hands below shoulder height	One hand above shoulder height	Two hands above shoulder height
	Score	1	2	3
	AC distribution	AC1 29; AC2 23; AC3 19; AC4 14	AC1 23; AC2 17; AC3 19; AC4 25	AC1 20; AC2 13; AC3 17; AC4 34
NIOSH	***Description***	Start or end height (V) of 750 mm	Start or end height (V) of 0 mm	Start or end height (V) of 2000 mm
	Score	LI = 1	LI = 1.29	LI = 1.6
	Description	Lift distance (D) of 250 mm	Lift distance (D) of 1750 mm	
	Score	LI = 1	LI = 1.18	

4.7.4 Trunk asymmetry

Table 38 compares the different methods of assessing the postural asymmetry that occurs in manual handling. This can have several sources: trunk axial rotation, trunk lateral flexion, and upper limb asymmetry. It is distinct from trunk flexion in the sagittal plane (‘back bending’). Also, a task may be asymmetrical, but if the worker moves his or her feet, postural asymmetry may not occur.

The MAC scores trunk asymmetry separately to trunk flexion but does not distinguish between trunk rotation and trunk lateral flexion. The QEC, on the other hand, combines the trunk asymmetry assessment with the assessment of trunk flexion so a posture that is both bent and twisted will be coded the same as one that is either bent or twisted. REBA takes the approach of increasing the trunk score by 1 if either form of trunk asymmetry occurs. OWAS treats the combination of trunk flexion and rotation as significantly worse than either trunk flexion by itself or trunk rotation by itself. It does not take account of trunk lateral flexion.

NIOSH uses a linear relationship to decrease the RWL as task asymmetry increases. Task asymmetry is, strictly, not a measure of trunk asymmetry since it includes asymmetry due to upper limb postures. LI values were calculated for asymmetries of 0° and 135°, which are the ends of the range specified by the equation. As before, the load was set to 23 kg and all other multipliers to 1.0.

Table 23 Trunk twisting/sideways bending scoring

		Category 1	*Category 2*	*Category 3*
MAC lifting flowchart	***Description***	Little or none	Trunk twisting OR sideways bending	Trunk twisting AND sideways bending
	Colour	Green	Amber	Red
	Score	0	1	2
QEC	***Description***	Almost neutral	Moderately twisted or side bent	Excessively twisted or side bent
	Score	1	2	3
REBA	***Description***	Trunk upright	Trunk upright and twisted or side flexed	0-20° trunk flexion and twisted or side flexed
	Score	1	2	3
OWAS	***Description***	Trunk straight	Trunk twisted	Trunk bent and twisted
	Score	1	3	4
	AC distribution	AC1 44; AC2 17; AC3 2; AC4 0	AC1 28; AC2 7; AC3 10; AC4 18	AC1 0; AC2 10; AC3 15; AC4 38
NIOSH	***Description***	0° task asymmetry	135° task asymmetry	
	Score	LI = 1	LI = 1.76	

4.7.5 Quality of grip

Table 39 compares the way that the different tools compare the quality of the coupling between the person and the object being handled. Neither QEC nor OWAS consider this factor. The MAC definitions are clearly designed to follow those of the NIOSH equation. The REBA definitions are more focussed on patient handling. NIOSH LI values were calculated assuming a load of 23 kg and with all other multipliers set to 1.0.

Table 24 Grip scoring

		Category 1	*Category 2*	*Category 3*	*Category 4*
MAC lifting flowchart	***Category***	Good	Reasonable	Poor	
	Description	Container with well-designed handles or handholds, fit for purpose. Loose parts enabling comfortable grip.	Containers with poorer handles or handholds. Fingers to be clamped at 90° under the container.	Containers of poor design. Loose parts, irregular objects, bulky or difficult to handle. Non-rigid sacks or animate objects (animals and people).	
	Colour	Green	Amber	Red	
	Score	0	1	2	
REBA	***Category***	Good	Fair	Poor	Unacceptable
	Description	Well-fitting handle and a midrange power grasp.	Hand hold acceptable but not ideal or coupling is acceptable via another part of the body.	Hand hold not acceptable although possible.	Awkward, unsafe grip, no handles. Coupling is unacceptable using other parts of the body
	Score	0	1	2	3
NIOSH	***Category***	Good	Fair	Poor	
	Description	Optimal containers, with optimal handles or hand-holds. Loose or irregular objects grippable without excessive force or deviations or awkward postures.	Optimal containers, with non-optimal handles or hand-holds or without handles or hand-holds, or loose or irregular objects grippable with 90° finger flexion.	Non-optimal containers or loose or irregular objects that are bulky, hard to handle, or have sharp edges or non-rigid bags.	
	Score	LI = 1	LI = 1.05	LI = 1.11	

4.7.6 Other factors

Table 40 lists three factors considered only by the MAC: Postural constraints; Floor surface; and Other environmental factors. Constraints on posture include factors such as restricted foot placements or lack of headroom.

Table 25 Other factors in the MAC lifting flowchart

		Category 1	*Category 2*	*Category 3*
Postural constraints	***Description***	None	Restricted	Severely restricted
	Colour	Green	Amber	Red
	Score	0	1	3
Floor surface	***Description***	Dry and in good condition	Dry but in poor condition or uneven	Contaminated, wet, sloping or unstable
	Colour	Green	Amber	Red
	Score	0	1	2
Other environmental factors	***Description***	Extreme temperatures	Strong air movements	Inadequate lighting
	Colour	Amber	Amber	Amber
	Score	+1	+1	+1

5 DISCUSSION AND CONCLUSIONS

Measuring exposure to musculoskeletal risk factors is both conceptually and practically complex. This study has shown that a wide variety of methods of assessing risk from manual handling have been developed and described in the scientific literature. There are clear links between the methods reviewed with concepts and scoring systems from previous methods being reused, often in modified forms, in later methods. Most rely on snapshot assessments of single postures, often those believed to be hazardous or problematic but time sampling and weighting of measurements are possible though time consuming, and offer further difficulties in interpretation.

HSL/HSE have developed a further tool for assessment of manual handling operations - the Manual handling Assessment Charts (MAC). For each of three types of manual handling - lifting, team lifting by up to four persons, and carrying, a flowchart guides the user through an assessment and provides indications of levels of risk, using a “traffic light” system to assign colour codes and associated numerical values to each factor considered. The conceptual model underlying the MAC assumes that the risk factors, except load and frequency of handling, do not interact. The differential weighting of the numerical scores assigned to the colour codes for the different risk factors, in theory, should allow levels of risk to be assigned to particular total scores and hence allow boundaries between risk zones to be determined. However, following an earlier review of the charts, no attempt has been made to assign meaning to the totals of the scores from individual risk factors.

The benchmarking exercise carried out by a small number of ergonomists experienced in assessing manual handling operations showed that the MAC was ranked as one of the easiest of the five tools to use and one of the most appropriate methods for assessing manual handling operations. The exercise also showed that there were no systematic differences in how the different methods ranked the levels of risk of the tasks studied but the way that the severity of tasks was ranked was random. The tools appear to be assessing risk in different ways and so cannot be compared easily.

The status of the different tools is variable. The MAC is still under development and has not yet been made public. The QEC has been presented at a number of scientific conferences (Li and Buckle, 1997, 1998, 2000) and published as an HSE Contract Research Report (Li and Buckle, 1999b). It has also been presented at HSE sponsored seminars. However, it has not yet appeared in the peer-reviewed scientific literature except for a mention by the same authors in a review of techniques for assessing exposure to WMSDs (Li and Buckle, 1999a). The personal website of Dr Li (Li, 2002a) states that a revised manuscript on the QEC (Li and Buckle, 2000) has been submitted for publication. Also, HSE is sponsoring further work to improve the scope, usability and validity of the QEC (Buckle, 2002).

Of the other tools, REBA was published in the peer-reviewed literature in 2000 (Hignett and McAtamney, 2000) after a number of earlier conference presentations (Hignett and McAtamney, 1997; McAtamney and Hignett 1995,1997). OWAS was published in the peer-reviewed literature as long ago as 1977 (Karhu *et al*., 1977, 1981), and has been widely used since (e.g., Vedder 1998). The 1991 revision of the NIOSH equation was published in the peer-reviewed literature by Waters *et al.* (1993) though more extensive descriptions occur in NIOSH publications (NIOSH, 1981, Waters *et al.*, 1994).

OWAS, REBA and the QEC use ordinal scoring systems and then combine the scores for different risk factors. OWAS and REBA use “Action Categories” based on four and five point ordinal scales to give an assessment of the urgency of remedial action for the task. The OWAS Action Categories are based on expert judgements of the urgency of remedial action for each posture combination. The REBA scoring system was based on the RULA system (McAtamney and Corlett, 1993) and modified through judgements of experts (Hignett and McAtamney, 2000). This scoring system can be approximated by an additive model.

By contrast, the QEC has an exact mathematical model implicit in its structure with variations in weighting between factors. Originally a series of scores were calculated for different regions of the body. Since then Action Levels have been proposed which are related to the total score across all parts of the body. These Action Levels were suggested by an M.Sc. student (Brown, 2001) based on a comparison with RULA. Li, (2002b) has published these Action Levels on the QEC site on the Internet but has not published a justification for them. The original HSE Contract Research Report (Li and Buckle, 1999b) described the QEC as a tool for evaluating change in exposure to risk factors, not a method of assigning absolute risk. It is unfortunate that the authors have abandoned their previous caution with regard to this aspect, especially since they noted (Li and Buckle, 1999a) that "the 'score system' is at this time largely hypothetical and needs to be validated through epidemiological studies".

The 1991 NIOSH lifting equation is based on a multiplicative model of risk relative to a reference load of 23 kg where the risk is modified as six parameters vary. NIOSH has taken a fundamentally different approach to the scoring systems of the other risk assessment tools. Firstly, they have produced a parametric equation based on measurements of parameters of the task, not the posture of the individual. Secondly, they have attempted to predict a recommended weight limit that would be safe for most workers performing the task. The equation uses the Lifting Index to assess the risk of an actual task relative to the risk of handling the 23 kg reference weight of the Load Constant in particular, ideal circumstances.

Underlying the MAC and the QEC are additive models and while it is possible to convert the NIOSH equation into an additive model, the form is quite different due to it calculating a relative risk. It is therefore difficult to make simple comparisons between risk factors and scoring systems, but both additive and multiplicative models are valid approaches to the issue of assessing risk of manual handling so long as the models are restricted to risk factors for a single part of the body. The clear need is for risk assessment tools to distinguish between risk to the low-back and risks to the upper limbs. On this basis both REBA and the QEC are flawed because they create overall scores that are effectively tallies of the risk factors present, even though some relate specifically to the upper limb and some specifically to the low back.

The MAC has the advantage that it is focussed on the risk of injury to the low back from manual handling and does not attempt to score risk to the upper limb. Also, the approach adopted with the MAC of assessing when an individual risk factor is beyond safe limits without attempting to assign an overall risk level to the whole task is a much sounder basis for risk assessment than any method of assessing the overall risk of the task since any real job is likely to contain several independent risks.

Like the other tools, the MAC has not yet been validated as a predictor of risk of injury or sickness absence . HSL are currently running a prospective study on behalf of HSE's Health Directorate to validate the 1991 NIOSH Lifting Equation using sickness absence data and job parameter data. It should therefore be possible to use these data to validate the ability of the MAC to predict work absence due to low back pain.

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