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The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders

Geoffrey David[a,*], Valerie Woods[a], Guangyan Li[b], Peter Buckle[a]

[a]*Robens Centre for Health Ergonomics, European Institute of Health and Medical Sciences, University of Surrey, Guildford, Surrey GU2 7TE, UK*
[b]*Human Engineering Ltd. Shore House, 68 Westbury Hill, Westbury-On-Trym, Bristol BS9 3AA, UK*

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Abstract

This paper describes the development and evaluation of the Quick Exposure Check (QEC), which is an observational tool developed for Occupational Safety and Health (OSH) practitioners to assess exposure to risks for work-related musculoskeletal disorders and provide a basis for ergonomic interventions. The tool is based on epidemiological evidence and investigations of OSH practitioners' aptitudes for undertaking assessments. It has been tested, modified and validated using simulated and workplace tasks, in two phases of development, with participation of 206 practitioners. The QEC allows the four main body areas to be assessed and involves practitioners and workers in the assessment. Trials have determined its usability, intra- and inter-observer reliability, and validity which show it is applicable to a wide range of working activities. The tool focuses primarily on physical workplace factors, but also includes the evaluation of psychosocial factors. Tasks can normally be assessed within 10 min. It has a scoring system, and exposure levels have been proposed to guide priorities for intervention. Subsequently it should be used to evaluate the effectiveness of any interventions made. The QEC can contribute to a holistic assessment of all the elements of a work system.

Keywords: Ergonomics; Measurement; Workplace.

1. Introduction

Work-related musculoskeletal disorders (WMSDs) are a common health problem and a major cause of disability (Bernard, 1997; Smith et al., 2001; European Agency for Safety and Health at Work, 1999). A range of workplace, individual, and psychosocial risk factors are associated with the development of WMSDs. Workplace risk factors include the physical demands imposed by performing the task, such as posture adopted, force applied, frequency and repetition of movement, task duration and vibration experienced (Bernard, 1997; Smith et al., 2001; European Agency for Safety and Health at Work, 1999; Burdorf and Sorock, 1997; Kilbom, 1994a; Melhorn, 1999). Individual risk factors include age, gender, anthropometry, muscle strength and physical fitness (Armstrong et al., 1993; Punnett and Herbert, 2000). Psychosocial factors such as work or time pressures, lack of social support and poor job satisfaction can contribute to WMSDs (Bernard et al., 1994; Lee et al., 1989; Toomingas et al., 1997; Hoogendoorn et al., 2000; Woods, 2005).

As a result of these findings, there has been major interest in assessing exposure to risk factors associated with WMSDs, and subsequently to conduct ergonomic interventions in the workplace. Exposure assessment has concentrated on the back, shoulders, upper limbs and neck, because most of the reported work-related injuries are in these body regions.

Current techniques for assessing exposure to risk factors associated with WMSDs include self-reports, observational methods, and direct measurement (Li and Buckle, 1999a). Despite the usefulness of these methods for exposure assessment, limitations have also been identified (David, 2005), e.g. Occupational Safety and Health (OSH) practitioners' needs and workers' participation have rarely been

*Corresponding author. Tel.: +44 1483 689213; Fax: +44 1483 689395.
E-mail address: g.david@surrey.ac.uk (G. David).

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considered. Exposure assessment tools are required that practitioners can use in the workplace. This paper describes the development and evaluation (usability, reliability and validity) of the Quick Exposure Check (QEC) and provides the reader with information about the participative approach adopted and the scientific foundation that underpins its use in the workplace. The QEC has been designed for use by OSH practitioners to assess exposure to risk factors for WMSDs and to provide a basis for ergonomic intervention at the workplace. Subsequently it should be used to evaluate the effectiveness of any interventions made.

2. Methods used for the development and evaluation of QEC

The initial construction and evaluation of the QEC was undertaken in Phase 1 (1996–1998) (Li and Buckle, 1998, 1999b; Buckle and Li, 1998). Following a period of use by practitioners, its content was evaluated and refined, and its presentation format reviewed in Phase 2 (2000–2003) (David et al., 2005). Fig. 1 shows the stages in the development process. During both phases a participative iterative ergonomics approach was adopted based upon trials and feedback from 206 practitioners.

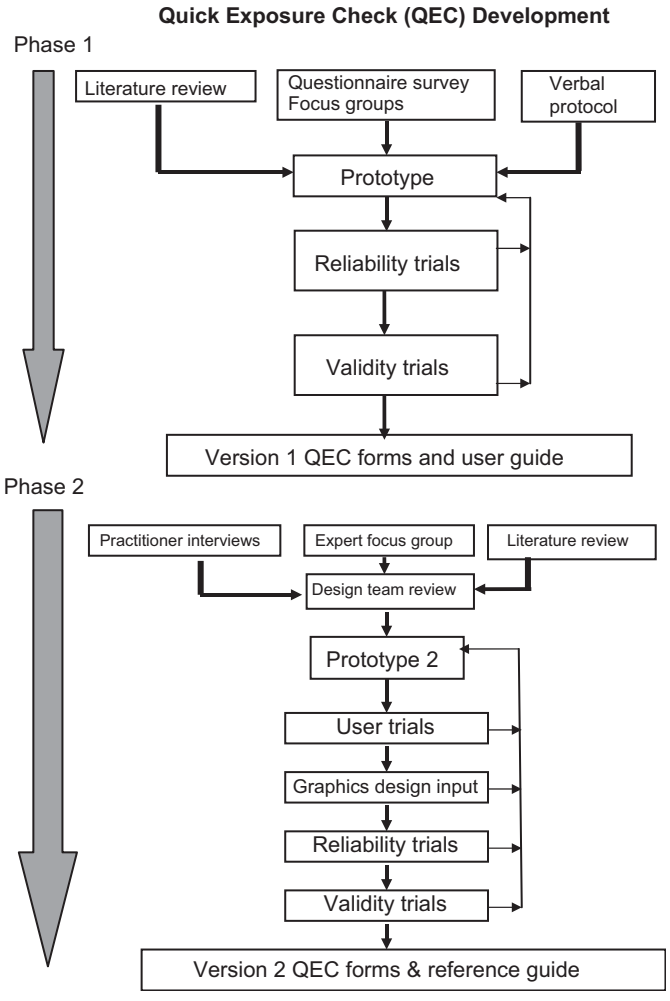

Fig. 1. QEC development process.

2.1. Phase 1

2.1.1. Literature review

Epidemiological evidence regarding the role of physical and psychosocial factors in the development of WMSDs was collated to identify and prioritise risk factors for inclusion in the QEC. Current techniques for assessing physical exposure were also reviewed to help form the strategy for the development of the tool. The sources of information utilised in the tool construction are cited in Section 3.

2.1.2. Questionnaire survey

Ninety-three practitioners provided opinions about the use of existing exposure assessment methods, the problems encountered in making assessments in the workplace, and their requirements for a new assessment tool.

2.1.3. Focus groups

Five focus groups, comprising a total of 40 OSH practitioners, reviewed the problems and difficulties they encountered with existing exposure methods and their needs and recommendations for a new tool.

2.1.4. Verbal protocol

Eight practitioners made exposure assessments whilst observing video film of three simulated tasks i.e. manual assembly, manual handling, VDU work (performed by 6 subjects). Presentation order was randomised and each practitioner made verbal assessments. These were recorded and analysed to establish the terminology preferred and the order in which the various body areas were assessed.

2.1.5. Reliability trials

Eighteen practitioners viewed video recordings of 18 industrial static and dynamic activities (combinations of high repetition and low force, and low repetition with high force for both seated and standing postures were observed). Inter-observer reliability was determined by comparing the variation between the practitioners' scores for each task and those determined from SIMI* 3D (Reality Motion System, GmbH, Germany) computerised motion analysis (Cohen's κ-coefficient, percentage agreement).

A test–retest study was conducted with 8 practitioners who assessed the same set of 18 recorded tasks twice at an interval of three weeks. Intra-observer reliability was determined by comparing the 2 sets of scores for each individual across the range of tasks assessed (Cohen's κ-coefficient, Spearman's coefficient, percentage agreement).

2.1.6. Validity trials

The validity of the QEC assessment was determined by comparing (percentage agreement) 18 practitioners' QEC scores of 4 task simulations with the results of the SIMI*

3D computerised motion analysis. In addition, comparison was made (percentage agreement) between the results of 6 practitioners' QEC scores for workplace tasks (59 in total) with expert assessments made from video film.

2.2. Phase 2

2.2.1. Practitioner interviews

A structured telephone interview was carried out with 7 current users to determine their feedback about using the QEC. A range of issues was reviewed (e.g. terminology, training, the scoring system, factors assessed, task and job definition).

2.2.2. Expert focus group

Following the assessment of 5 manual tasks, 8 ergonomists reviewed the usability of the QEC, and identified areas where the tool or the guidance for practitioners could be improved.

2.2.3. Literature review

A literature survey was undertaken to identify recently published sources relevant to the construction evidence upon which the tool was based (see Section 3). Searches were performed of the electronic databases 'Ergonomics Abstracts' and OSH-ROM using appropriate key words.

2.2.4. Design team review

The data collected were used to identify issues relating to the presentation, terminology and scoring layout and revisions were made where appropriate. Different formats and representations for both the assessment form and the scoring sheet were devised and a prototype developed.

2.2.5. User trials

The prototype was evaluated by 10 practitioners who assessed a manual assembly task. Following this they completed questionnaires to evaluate the usability of the tool; this was followed by group discussion. Improvements to the assessment and scoring forms, and the enhanced Reference Guide were identified.

2.2.6. Graphics design input

Development work was carried out by a graphics designer on the format and presentation of the assessment forms and the Reference Guide. The usability of the improved versions of the QEC and the Reference Guide were tested by 12 practitioners and 7 ergonomists. Feedback to the designer enabled further refinements to be made.

2.2.7. Reliability trials

The Phase 2 trials were designed to complement the results of the extensive trials in Phase 1 using tasks shown on video film. Assessments were made of a smaller range of tasks in the workplace. Six practitioners, who undertake risk assessments, were given training on how to conduct a QEC assessment. This involved a trial assessment on a simulated task to familiarise the subject with the QEC process, together with subsequent discussion with the researchers, and the provision of the draft Reference Guide to read in the intervening period of at least 24 h before commencing the trial. The subject then observed 3 tasks (i.e. cleaning a floor using a buffing machine, pipetting whilst standing at a laboratory bench, word processing) on 2 separate occasions over a 3-day period; no other practitioner was present when the assessment was made. The performance of the worker at each task was standardised on both occasions. Feedback from practitioners about their use of the QEC was obtained using a questionnaire. Inter-reliability scores were determined (Kendall's coefficient of concordance) to assess the level of agreement between the 6 assessors.

2.2.8. Validity trials

Validation trials were undertaken with 7 practitioners at 6 organisations. Five tasks were identified, representing a range of activities, at each organisation (e.g. manual handling, computer work, manipulative assembly). The tasks were assessed by both the practitioner and by 2 experts from the study team. The responses of the worker to the QEC assessment were recorded following each assessment and the QEC scores were determined. Seven-point rating scales on 'ease of use', 'the applicability of the QEC to the workplace' and 'its value in conducting assessments' were completed by each practitioner. The QEC forms, Reference Guide and general assessment issues were then reviewed with each practitioner. The level of agreement between the practitioners' and experts' scores were determined (Spearman's ρ) for each of the four body areas.

The data gathered using the above methods in Phases 1 and 2 are reported in Sections 3 and 4 concerning the development and evaluation of the QEC.

3. Development of the QEC

The practitioners requirements for an exposure tool identified in Phase 1 showed that it should be (i) simple, easy and quick to use, (ii) applicable to a variety of work situations, (iii) completed in 10–20 min, (iv) scientifically based, (v) comprehensive, (vi) reliable, and further that it should (vii) involve workers, (viii) have scores to measure the levels of exposure, and (ix) have instruction on how to use the tool/carry out assessments. The results of the verbal protocol identified that practitioners preferred to use descriptive words rather than defined angular ranges when assessing posture (Li and Buckle, 1998, 1999b). The improvements identified by practitioners in Phase 2 following extended use of the tool are shown in Table 1.

The data from both development phases resulted in a 3 stage QEC assessment process that required: (a) an observer to record the postures adopted and the frequency of movement of four body areas (Table 2) for the worker

Table 1
Improvements needed to Quick Exposure Check (identified by 7 practitioners) (David et al., 2005)

Improvement needed	Example of requirement
Changes to layout to improve ease of use at the workplace	• Combination of observer and worker questions on one page
Alteration to worker questions	• Space to record details about work organisational issues • Clarification of question terminology
Addition of other risk factors	• Whole body and hand/arm vibration
Changes to scoring system	• Improve transparency • Improve layout for easier use
Provision of improved guidance	• Role of QEC and conducting assessments • Obtaining representative samples • Advice on basic task analysis

Table 2
Risk factors assessed by the Quick Exposure Check with their comparative contribution to the score for each body area (Li and Buckle, 1999b)

	Static	Moving		Static or moving
Back			*Shoulder/arm*	
Load weight	2	3	Load weight	3
Duration	2	3	Duration	3
Posture	3	2	Posture	2
Frequency	–	2	Frequency	2
Wrist/hand			*Neck*	
Force	–	3	Duration	2
Duration	–	3	Posture	1
Posture	–	2	Visual demand	1
Frequency	–	2		

performing a task (Section 3.1), (b) information to be gathered about the task in discussion with the worker (Section 3.2), and (c) a score to be calculated for each body area dependant upon the risk factors assessed and their respective exposure level (Table 2) (Section 3.3).

The resulting design for the QEC assessment (Section 3.4) and score calculation are shown in Figs. 2 and 3. This assessment provides the basis for prioritisation of interventions and their evaluation.

The construction was therefore based on the practitioners' requirements and the epidemiological evidence; these are described below for each factor assessed by the QEC.

3.1. Exposure assessment by the observer

3.1.1. Back posture

Trunk flexion is associated with reports of transient local muscle fatigue and low back pain (LBP). Additionally, lateral bending or axial twisting of the spinal column during manual handling can also increase risk of LBP (Keyserling et al., 1988).

Flexion of less than 20° has not been associated with LBP for workers in long periods of employment (Aarås, 1994). 'Mild' cases of work-related back disorders were reported for postures of between 21° and 45° and 'severe' cases found with flexion of >45°, or twisting/lateral bending of >20° (Punnett et al., 1991). A posture range of 21°–45°, however, was found to be too narrow for observers to judge accurately in user trials. Therefore, the QEC posture categories were defined as 0–20°, 21°–60° and >60°, as used in other assessment tools (McAtamney and Corlett, 1993).

Three corresponding descriptive terms were chosen to describe these categories, 'almost neutral', 'moderately flexed or twisted', and 'excessively flexed or twisted', based upon user feedback about appropriate discriminatory terminology for back posture exposure levels.

3.1.2. Back movement

An increased risk of LBP is associated with increased frequency of back movement when carrying out manual handling tasks (Bernard, 1997). For tasks other than manual handling, static postural loading has been shown to be a risk factor for LBP, especially when combined with long work duration (Westgaard and Aarås, 1984; Carter and Banister, 1994).

The OSHA ergonomics standard (2000) categorised back movement frequency into two exposure levels: less than or more than 5 times per minute. To increase the sensitivity of the QEC, three categories were defined to assess back movement: 1–5, 6–10 and >10 times per minute. User trials showed that observers had difficulties distinguishing between frequencies close to category boundaries (Li and Buckle, 1999b). Therefore based on the 'verbal protocol' study, median values were used to categorise the three frequency levels. Corresponding descriptive terms were chosen to describe these categories i.e. 'infrequently' (around 3 times/min or less), 'frequently' (around 8 times/min), 'very frequently' (around 12 times/min or more). For tasks other than manual handling, the assessment was divided into two categories dependant upon the presence or absence of static postural load.

The results of Phase 2 surveys and trials revealed that some users were confused when assessing back movement. Therefore the question layout and order was improved and clear guidance provided to enable the user to differentiate between manual handling and other more static tasks. Further, this distinction was emphasised in the QEC Reference Guide (David et al., 2005).

3.1.3. Shoulder/arm posture

Working with elevated upper arms, especially at or above shoulder height, is recognised as a risk factor for shoulder WMSDs (Wiker et al., 1989) as the load on shoulder musculature increases with greater elevation

Worker's name _____ Date _____

Observer's Assessment

Back

A When performing the task, is the back *(select worse case situation)*

- A1 Almost neutral?
- A2 Moderately flexed or twisted or side bent?
- A3 Excessively flexed or twisted or side bent?

B Select ONLY ONE of the two following task options:

EITHER

For seated or standing stationary tasks. Does the back remain in a static position most of the time?

- B1 No
- B2 Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the movement of the back

- B3 Infrequent (around 3 times per minute or less)?
- B4 Frequent (around 8 times per minute)?
- B5 Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C When the task is performed, are the hands *(select worse case situation)*

- C1 At or below waist height?
- C2 At about chest height?
- C3 At or above shoulder height?

D Is the shoulder/arm movement

- D1 Infrequent (some intermittent movement)?
- D2 Frequent (regular movement with some pauses)?
- D3 Very frequent (almost continuous movement)?

Wrist/Hand

E Is the task performed with *(select worse case situation)*

- E1 An almost straight wrist?
- E2 A deviated or bent wrist?

F Are similar motion patterns repeated

- F1 10 times per minute or less?
- F2 11 to 20 times per minute?
- F3 More than 20 times per minute?

Neck

G When performing the task, is the head/neck bent or twisted?

- G1 No
- G2 Yes, occasionally
- G3 Yes, continuously

Worker's Assessment

Workers

H Is the maximum weight handled MANUALLY BY YOU in this task?

- H1 Light (5 kg or less)
- H2 Moderate (6 to 10 kg)
- H3 Heavy (11 to 20kg)
- H4 Very heavy (more than 20 kg)

J On average, how much time do you spend per day on this task?

- J1 Less than 2 hours
- J2 2 to 4 hours
- J3 More than 4 hours

K When performing this task, is the maximum force level exerted by one hand?

- K1 Low (e.g. less than 1 kg)
- K2 Medium (e.g. 1 to 4 kg)
- K3 High (e.g. more than 4 kg)

L Is the visual demand of this task

- L1 Low (almost no need to view fine details)?
- *L2 High (need to view some fine details)?

* *If High, please give details in the box below*

M At work do you drive a vehicle for

- M1 Less than one hour per day or Never?
- M2 Between 1 and 4 hours per day?
- M3 More than 4 hours per day?

N At work do you use vibrating tools for

- N1 Less than one hour per day or Never?
- N2 Between 1 and 4 hours per day?
- N3 More than 4 hours per day?

P Do you have difficulty keeping up with this work?

- P1 Never
- P2 Sometimes
- *P3 Often

* *If Often, please give details in the box below*

Q In general, how do you find this job

- Q1 Not at all stressful?
- Q2 Mildly stressful?
- *Q3 Moderately stressful?
- *Q4 Very stressful?

* *If Moderately or Very, please give details in the box below*

* *Additional details for L, P and Q if appropriate*

* **L**

* **P**

* **Q**

Fig. 2. QEC assessment form.

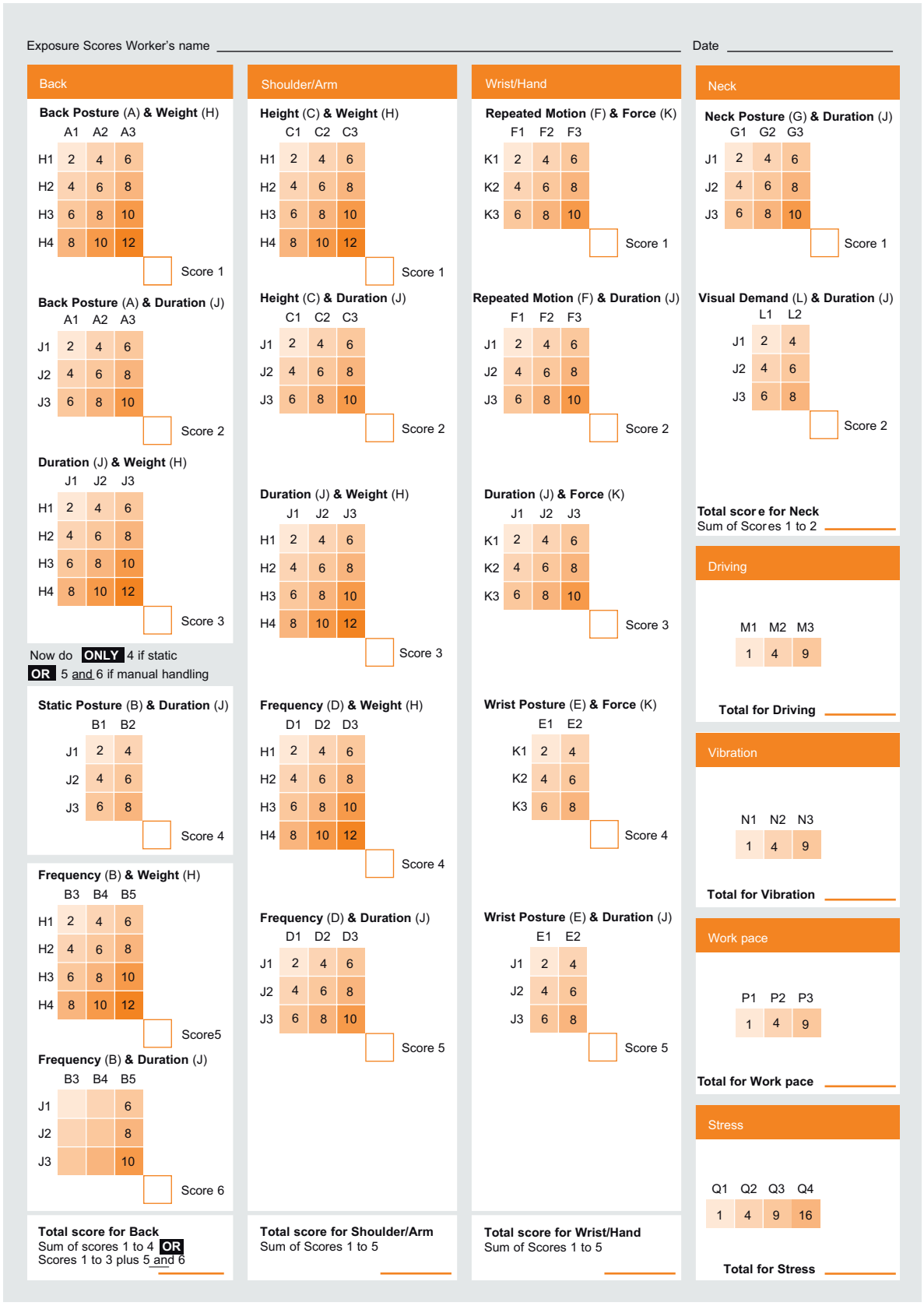

Fig. 3. QEC scoring form.

(Sigholm et al., 1984). Work involving repeated or sustained flexion of the arm of greater than 60° is associated with shoulder disorders (Bernard, 1997). When assessing arm posture, differentiation has been made between below or above the shoulder (Fransson-Hall et al., 1995), using a criterion angle of greater than 90° between the body and upper arm (Ketola et al., 2001).

Three levels of exposure were selected for the assessment of shoulder/arm posture in the QEC, i.e. at/below waist height, at chest height, above shoulder height and following feedback from users in Phase 2, the posture of the shoulder/arm was referenced specifically to the position of the hands (European Agency for Safety and Health at Work, 1999).

3.1.4. Shoulder/arm movement

Highly repetitive shoulder/arm movement increases the risk of shoulder tendon disorders (Bernard, 1997). Further, it was reported that shoulder movement frequencies greater than 2.5 per min were associated with WMSDs, however no further data on the frequency at which the level of risk increased significantly were reported (Kilbom, 1994a, 1994b). As a result, exposure assessment in the QEC was based upon the practitioners' perceptions about the movement pattern of the arm, rather than on the number of movements within a given period. This approach has been supported by other investigators (Latko et al., 1999). Three descriptive terms were chosen to categorise increasing level of exposure, i.e. infrequently, frequently, and very frequently. In Phase 2, the question was revised to encompass any continuous movement of the shoulder/arm, not solely repetitive, cyclical actions.

3.1.5. Wrist/hand posture

There is strong evidence to indicate that awkward wrist/hand posture is a risk factor for the development of wrist disorders, especially in combination with other factors such as force, repetition and duration (Bernard, 1997; Malchaire et al., 1996).

The prevalence of wrist problems increases for tasks performed with the wrist deviated/flexed/extended from neutral. The definition of a neutral wrist posture has varied between studies: as less than 25° of flexion/extension and 10° of ulnar deviation (Moore and Garg, 1994), as less than 45° for flexion/extension, 15° for radial deviation and 20° for ulnar deviation (Colombini, 1998), and the boundary angle between a 'good' and 'bad' wrist posture as 20° (McAtamney and Corlett, 1993).

In the QEC, a critical angle of 15° was selected for the assessment of all wrist postures. The results of the 'verbal protocol' study showed that observers had difficulty in distinguishing between wrist postures above or below this angle and it was decided that exposure levels should not be assessed by the estimation of a specific angular value (Li and Buckle, 1999b). Other investigators have confirmed that it is not possible to estimate wrist angle very precisely in the workplace (Ketola et al., 2001). Therefore, two linguistic descriptors 'almost a straight wrist' or 'with a deviated or bent wrist' were used. These terms were sufficiently sensitive to differentiate between critical differences in wrist posture (Li and Buckle, 1999b).

3.1.6. Wrist/hand movement

Repetition is reported as a risk factor for carpal tunnel syndrome and repetitive strain injury (Latko et al., 1999; Malchaire et al., 1996), especially in combination with other factors such as force and posture. 'Highly repetitive' tasks have been defined as those with a work cycle time of less than 30 s or when a similar motion pattern occurs for more than 50% of the cycle time (Silverstein et al., 1987). Kilbom (1994a) reported that low levels of wrist exposure encompassed movement rates of up to 10 times per minute. Ciriello et al., (2001) found increasing musculoskeletal symptoms with rising rates of wrist/hand motion.

A regular pattern of work may not always occur which can make the assessment of movement frequency difficult without extensive observation. Therefore in the QEC wrist/hand repetitive movement is assessed by rate i.e. number of times a similar motion pattern is repeated each minute. Based upon practitioners' needs for simplicity and usability, the frequency of wrist/hand movement is categorised into 3 levels ($\leqslant$10, 11–20, $>$20 times/min).

3.1.7. Neck posture

There is strong evidence that awkward neck posture held for a prolonged time is a risk factor for neck or neck/shoulder problems (Bernard, 1997). Tilting the head/neck more than 30° greatly increased the rate of fatigue in the neck extensors. At an angle of around 15°, however, only minimal changes were reported in either EMG or subjective discomfort even after working for 6 h (Chaffin, 1973). Conversely, it was reported that extended periods spent with the neck in 15° of flexion were associated with significant levels of neck and neck/shoulder disorders (Ohlsson et al., 1995).

User trials indicated that it was difficult for observers to determine a specific neck angle solely by observation. Practitioners preferred to use descriptive terms such as 'bent or twisted excessively' rather than angular values (Li and Buckle, 1999b) and they were used in the QEC to distinguish between the two levels of exposure. The Phase 2 trials revealed that some users were confused about the term 'excessively' and it was excluded, therefore, from the question.

3.2. Exposure assessment data gathered from the worker

3.2.1. Maximum weight handled

Handling heavy loads or high force applications are risk factors for WMSDs especially for the low back, shoulder/arm and wrist/hand (Bernard, 1997). LBP has been associated with handling loads of varying weight, e.g. 5 kg (Punnett et al., 1991), more than 10 kg at least once a day (Ohlsson et al., 1995), 20 kg twice a day (Frymoyer

et al., 1983). The maximum acceptable weight for lifting under optimal conditions defined in the NIOSH Lifting Equation is between 20 and 23 kg (Waters et al., 1993). Therefore uncertainty exists about whether a load is 'light' or 'heavy' (Genaidy et al., 1998), and the level of physical strength required to ensure that the exposure level is minimal (Kumar, 2001). Different ranges have been proposed for categorising load weight:

- 0–2 kg, 2–10 kg, >10 kg (McAtamney and Corlett, 1993);
- 1–5 kg, 6–15 kg, 16–45 kg, >45 kg (Kilbom, 1994b);
- <10 kg, 10–20 kg, >20 kg (Kivi and Mattila, 1991).

In the QEC, four levels, i.e. light [5 kg or less], moderate [6–10 kg], heavy [11–20 kg], very heavy [>20 kg], were selected to increase sensitivity for this factor.

In Phase 2, the question terminology was clarified by referring specifically to the weight borne by the worker. Additionally, it was emphasised that the worker's response should be based on their perceptions of the load, not the actual weight although this may be used to supplement the worker's assessment.

3.2.2. Task duration

Task duration is a risk factor for WMSDs of the back, shoulder/arm, hand/wrist and neck (Bernard, 1997; Spurgeon et al., 1997). The OSHA ergonomics standard (2000) defined 'more than 2 consecutive hours per work day' as critical when found in combination with other risk factors. When daily exposure time exceeds 4 h, the rates of WMSDs increase in the back and shoulder/neck particularly for seated tasks (Washington State Department of Labour and Industries, 2000; Winkel and Westgaard, 1992). Three levels of exposure were defined in the QEC for task duration i.e. less than 2 h, 2–4 h, more than 4 h.

3.2.3. Hand force exertion

Forceful hand exertions during work tasks are associated with increased risk of upper limb disorders (Bernard, 1997). Occupations requiring forceful grasping are associated with a high incidence of carpal tunnel syndrome (CTS) (Bernard, 1997). Different critical levels have been proposed for hand force:

- significant increases in CTS symptoms were found in jobs with a mean hand force of $\geqslant$3 kg (Chiang et al., 1993)
- 'high-force' jobs categorised as those with mean hand force levels of >4 kg, and 'low-force' jobs were those with <1 kg (Silverstein et al., 1986)
- high hand force was defined as 4.5 kg (Ketola et al., 2001).

Three levels of exposure were identified in the QEC for the maximum force exerted by one hand i.e. low (less than 1 kg), medium (1–4 kg), high (more than 4 kg). User trials indicated that these levels were satisfactory but in practise the actual load transferred can be different from the force exerted by hand. It is necessary therefore to record the worker's perception of the effort involved. Measurement of force levels can be used to inform an intervention but only to supplement the worker's perceptions. In Phase 2, the question terminology was clarified by removing 'single or double handed'.

3.2.4. Visual demand of the task

The level of visual demand significantly influences neck flexion angle (Li and Haslegrave, 1999), and neck posture is strongly associated with neck disorders (Ohlsson et al., 1995).

Neck posture angles can be difficult to assess. It is easier, however, to ask the worker if the visual demand of the task is high. Two levels of exposure were identified i.e. high (need to view some fine details) and low (almost no need to view fine details). In Phase 2, the form layout was improved to allow more detail to be recorded for this factor.

3.2.5. Vibration

Exposure to whole-body vibration is associated with LBP and exposure to hand/wrist vibration is associated with CTS and hand-arm vibration syndrome (Bernard, 1997). Specialist equipment is required to measure vibration comprehensively. Therefore the practical approach adopted in the QEC is to ask workers to estimate the duration of their exposure to vibration (i.e. less than 1, 1–4, more than 4 h per day). As a result of further evidence (Johanning, 2000; Bovenzi, 1998), separate questions were introduced in Phase 2 for whole body vibration (during driving at work) and hand/arm vibration (when using hand tools).

3.2.6. Difficulty keeping up with work

Time pressure and machine-paced jobs are associated with job dissatisfaction, fatigue, and mental/physical ill-health (Polanyi et al., 1997; European Agency for Safety and Health at Work, 2000). In the QEC, workers are asked how frequently they have difficulty keeping up with their work, using three exposure categories i.e. never, sometimes, often. In Phase 2, the form layout was improved to allow more detail to be recorded for this factor.

3.2.7. Stress

Stress has been identified as an important factor in the development of WMSDs (Carayon and Lim, 1999; Bongers et al., 2002) and subjective perceptions outweigh what other behavioural and performance measures may indicate. In the stress process, an individual's cognition and subjective appraisal of a potential risk factor is considered to be crucially important (Rydstedt et al., 2004).

In the QEC, workers were asked about their perception of how stressful they found their work using four exposure categories i.e. not at all, low, medium, high. In Phase 2, the question was improved by asking the worker about their

perception of the stress in their overall job, and the terminology was clarified based upon new categories (Smith et al., 2000), i.e. not at all stressful, mildly stressful, moderately stressful, very stressful. In addition, the worker may be asked for more information about this aspect of the job, and the form layout was improved to allow more detail to be recorded.

3.3. The exposure scoring system

The scientific literature suggests that WMSDs develop as a result of risk factors working in combination and that the overall impact is greater than the sum of the separate effects, for example:

- combinations of high levels of force and high levels of repetition on hand/wrist symptoms (Silverstein et al., 1987; Ciriello et al., 2001);
- combinations of posture, frequency of lifting, and load on LBP (Marras et al., 1995); and
- combinations of physical and psychosocial factors on the development of neck and upper limb disorders (Devereux et al., 2002).

Table 3
Proposed priority levels for Quick Exposure Check scores (David et al., 2005)

Exposure factor	Exposure level			
	Low	Moderate	High	Very high
Back (static)	8–14	16–22	24–28	30–40
Back (moving)	10–20	22–30	32–40	42–56
Shoulder/arm	10–20	22–30	32–40	42–56
Wrist/hand	10–20	22–30	32–40	42–56
Neck	4–6	8–10	12–14	16–18
Driving	1	4	9	—
Vibration	1	4	9	—
Work pace	1	4	9	—
Stress	1	4	9	16

It is widely acknowledged therefore, that as different risk factors almost always interact in the workplace they should not be assessed independently. Despite these findings, there is still insufficient data to define exactly how exposures to different risk factors should be combined and weighted with respect to their contribution to WMSDs (Li and Buckle 1999a). The QEC scoring system was developed, therefore, as a practical compromise that allows exposure levels for different risk factors to be combined (Table 2 and Fig. 3). Practitioners and experts indicated that a straightforward scoring system (visually and mathematically) based solely upon addition was required. Even numbers were used to simplify calculations. Using larger increments was expected to improve the sensitivity of the score when comparing the results pre/post intervention. A matrix was developed to calculate a total score for each body area that indicated priorities for intervention.

In Phase 2, a transparent, vertical presentation style was developed. Priority levels for intervention were proposed (Table 3) to provide a basis for decision-making and communication within organisations.

3.4. Design of QEC forms and reference guide

Following revisions in Phase 2 the QEC incorporates a sheet for recording subject details; an assessment sheet with colour density coding to indicate increasing level of exposure to risk; and a scoring sheet that enables the contribution made by each exposure factor to the overall score for each body part to be readily identified (Fig. 2 and 3).

The design and content of the Reference Guide were revised extensively in Phase 2 to provide greater detail about using the QEC effectively in practise (David et al., 2005). It provides the practitioner with information on a range of topics such as, establishing priorities for assessment, illustrations of workplace postures, question interpretation, scoring the assessment, undertaking interventions and the need for re-assessment following change.

Table 4
Levels of agreement for Quick Exposure Check observations between and within observers in Phase 1 (Li and Buckle, 1999b)

Exposure factor	Inter-observer agreement (18 observers)		Intra-observer agreement (8 observers)		
	κ	Percentage agreement (%)	κ	Spearman's coefficient[a]	Percentage agreement (%)
Back posture	0.33	72.6	0.52	0.66	73.4
Back movement	0.17	71.2	0.50	0.66	76.0
Shoulder/arm posture	0.47	80.2	0.50	0.62	69.5
Shoulder/arm movement	0.38	79.3	0.53	0.64	74.2
Wrist/hand posture	0.0[b]	78.8	0.45	0.45	76.7
Wrist/hand movement	0.42	76.4	0.50	0.69	67.9
Neck posture	0.20	64.7	0.48	0.58	66.7

[a]All Spearman's coefficient statistically significant at $p \leqslant 0.001$ level.
[b]Methodological problems found in using κ.

4. Evaluation of the reliability, validity and usability of the QEC

The results of Phase 1 trials for inter-observer reliability and intra-observer reliability are shown in Table 4. The results of the validity studies are shown in Table 5 (Li and Buckle 1999b).

The inter-user reliability and validity were determined following the revisions made to the tool in Phase 2 (David et al., 2005). Inter-observer reliability was higher than generally found in Phase 1 (Table 6). Practitioners reported that the QEC was a straightforward and useful assessment tool; their suggestions, however, were used to make further refinements to the assessment and scoring forms, and the Reference Guide to finalise the current design. The results of the workplace validation trials are shown in Table 7 (David et al., 2005).

The practitioners' ratings (1 = very low, 7 = very high) indicated that the current version of the QEC was easy to use ($X = 6.2$, Sd .73), applicable to workplace assessments ($X = 5.8$, Sd .99) and valuable at work ($X = 6.0$, Sd. 1.0). The workers confirmed that the meaning of each question asked was clear. They considered worker involvement in the assessment process to be invaluable because of the additional insight provided about task performance and any difficulties encountered. They had no concerns about confidentiality when answering the QEC assessment questions.

Table 5
Percentage levels of agreement for Quick Exposure Check scores between observers and analysis from video film in Phase 1 (Li and Buckle, 1999b)

Exposure factor	Percentage agreement—Observers versus	
	SIMI analysis (%)	Expert analysis (%)
Back posture	87.0	54.2
Back movement	72.3	91.5
Shoulder/arm posture	85.2	81.3
Shoulder/arm movement	87.5	76.3
Wrist/hand posture[a]	—	84.7
Wrist/hand movement[a]	—	83.1
Neck posture[a]	—	76.3
Overall agreement	—	78.2

[a]Insufficient discrimination on video film for SIMI (Reality Motion System, GmbH, Germany) analysis.

5. Discussion

This paper reports on the development of an exposure assessment tool (QEC) through a process of participatory ergonomics and its evaluation in user trials. During the first phase a basic format was developed and its usability, reliability and validity extensively tested. During the second phase the tool format was radically revised on the basis of user experience and graphic design principles, and comprehensive guidance produced. Further, trials of the new version were conducted to complement the results of the usability, reliability and validity trials undertaken previously. The QEC has been found suitable for the assessment of a wide range of work activities.

In comparison with some other observational assessment tools, the QEC covers an extensive range of physical risk factors including load, posture, frequency of movement, visual demands and vibration for the four main body regions that have been identified following an extensive review of the scientific literature. It also recognises the importance of the evaluation of psychosocial risk factors (e.g. work stress, pace of work) in consultation with workers (David, 2005). The QEC involves both the practitioner and the worker in the assessment process, thereby encouraging a participative ergonomics approach to the introduction of workplace improvements.

The evaluation of reliability and validity is essential for the development of exposure assessment methods. The trials

Table 7
Level of agreement between 7 practitioners' and 2 experts' Quick Exposure Check scores (David et al., 2005)

Body area	Spearman's coefficient[a]
Back	0.87
Shoulder/arm	0.86
Wrist/hand	0.79
Neck	0.98

[a]All Spearman's coefficient statistically significant at $p \leqslant 0.01$ level.

Table 6
Inter-observer reliability (percentage agreement between 6 practitioners, Kendall's W) for Quick Exposure Check scores in Phase 2 (David et al., 2005)

Task	Percentage agreement							
	Back		Shoulder/arm		Wrist/hand		Neck	
	Posture	Motion	Posture	Motion	Posture	Motion	Posture/ motion	Kendall's W
Heavy manual	50	50	100	50	100	50	67	0.79
Repetitive	100	100	100	100	100	83	50	0.7
Static	100	100	83	33	100	67	83	0.6
Overall	83	83	94	61	100	67	67	—

using filmed tasks undertaken in Phase 1 demonstrated that the QEC has 'fair to moderate' levels of inter- and intra-observer reliability (Landis and Koch, 1977). Evaluations of inter-observer reliability using workplace tasks in Phase 2 demonstrated higher levels of agreement. It is anticipated that the reliability of the tool will increase as practitioners gain more experience in its use in the workplace. Similarly the trials in Phases 1 and 2 have demonstrated that the QEC is a valid tool for practitioners to use to assess exposure in the workplace.

The requirement for training has been recognised by the development of a comprehensive Reference Guide (available from www.hse.gov.uk/research/rrpdf/rr211.pdf). This should be read as the basis for undertaking workplace assessments and consulted subsequently to resolve queries. Although the use of the tool is intuitive, the level of inter-individual reliability will be increased by undertaking common assessments, with subsequent feedback and group discussion. A suitable programme to achieve this has been suggested in Appendix A. The development of a Web site providing case studies and an opportunity for discussion would further assist practitioners to apply the QEC effectively.

It was evident from the practitioners' survey that a scoring system was an essential requirement. At present this requirement cannot be met fully as the epidemiological evidence is insufficient. Therefore the current scoring system is an attempt to provide practitioners with a basis for making interventions based upon 'before and after' comparisons of exposure to the main risk factors. This system will require further revision and refinement based on its application in the workplace and in the light of future epidemiological research. Similarly the proposed priority levels for intervention can only be regarded as hypothetical at this time, and subject to revision following their application in practise. Nevertheless the high prevalence of WMSDs throughout industrialised countries (Bernard, 1997; Smith et al., 2001; European Agency for Safety and Health at Work, 1999) demonstrates the urgent need for practical exposure assessment tools to be available for use so that existing and new problems can be addressed.

Despite the above problems with scoring assessments quantitatively, the QEC has already been shown to be of value in assessing a wide range of workplace tasks from different industrial sectors (David et al., 2005). It has enabled potential changes to be prioritised, the possible improvements evaluated at the design stage and the effectiveness of the subsequent interventions in terms of reduced level of exposure determined (Li and David, 2004).

Following workplace trials, practitioners agreed that the QEC could form part of a comprehensive risk assessment within their organisations. Issues relating to organisational culture, training needs, work organisation and legal and regulatory rules should also be addressed when making workplace interventions (Moray, 2000).

6. Conclusion

The QEC is based on strong epidemiological evidence and practitioners' abilities to distinguish between levels of exposure in the workplace. It enables a range of the most important risk factors for WMSDs to be assessed. It is straightforward to use, applicable to a wide range of tasks and with practise, assessments can normally be completed within 10 min. Importantly, the QEC brings together the practitioner and the worker to make the assessment, thereby encouraging participative ergonomics. The QEC is of value in prompting improvements and in evaluating the benefits (reduction in exposure to WMSD risk factors) by providing a structured process to help prioritise the need for change. It can form a basis for communication between management, production engineers and designers when evaluating interventions and allocating resources to fund improvements.

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Appendix A. QEC training course

Based on a typical 1-day programme for 12–15 participants

Background [30 min]

- Musculoskeletal disorders—extent of the problem
- Ergonomics approach
- Assessment tools
- Practitioners needs

QEC [45 min]

- Development—why and how?
- What is available? Forms, Reference Guide, web resource
- 'Hands on' straightforward practical example with feedback based upon video

Using QEC effectively [1 h 45 min]

- Reference Guide
- Establishing priorities—various methods
- Doing the assessment—overview illustrated by local practical examples
- What is a task? Interaction with workers
- Recording the data
- Scoring [based upon earlier example] and its interpretation

Practical trials [2 h]

- Site visits—tasks chosen in advance
- Small teams undertake assessments

- Feedback
  - Findings of trials
  - Assessment problems
  - Interpreting the scores
  - Discussion of possible interventions and the need for re-assessment

Future use of QEC [30 min]

- Case study on an intervention and re-assessment
- Applications in your organisation

Close of course

- Feedback and evaluation

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