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Measuring the physical demands of work in hospital settings: Design and implementation of an ergonomics assessment ☆

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Abstract

Background: Assessing the physical demands of the heterogeneous jobs in hospitals requires appropriate and validated assessment methodologies.

Methods: As part of an integrated assessment, we adapted Rapid Entire Body Assessment (REBA), using it in a work sampling mode facilitated by a hand-held personal digital assistant, expanding it with selected items from the UC Computer Use Checklist, and developed a scoring algorithm for ergonomics risk factors for the upper (UB) and lower body (LB).

Results: The inter-rater reliability kappa was 0.54 for UB and 0.66 for LB. The scoring algorithm demonstrated significant variation (ANOVA $p<0.05$) by occupation in anticipated directions (administrators ranked lowest; support staff ranked highest on both scores). A supplemental self-assessment measure of spinal loading correlated with high strain LB scores ($r = 0.30$; $p<0.001$).

Conclusion: We developed and validated a scoring algorithm incorporating a revised REBA schema adding computer use items, appropriate for ergonomics assessment across a range of hospital jobs.

Keywords: Ergonomics assessment; Hospitals; Methodology

1. Background

Hospitals are complex systems relying on an extremely diverse group of occupations, many of which are physically demanding. In part for this reason, hospital employees are at particularly high risk for work-related musculoskeletal disorders (WRMDs). In 2001 in the US, the hospital industry reported the second highest absolute number of injuries and illnesses in the private sector (286,000), with an incidence rate of 8.8 per 100 full-time equivalent workers compared to 5.7 for all industries combined (US Department of Labor Bureau of Labor Statistics, 2002).

Even though musculoskeletal disorders are a major cause of disability across many industrial groups, the specific risk factors responsible for these conditions are only partially understood. As general categories, both physical and psychosocial stressors are recognized contributors to overall injury risk (Burdorf, 1992; Burdorf and van der Beek, 1999a, b, c; Forde et al., 2002; Hollmann et al., 1999; Kilbom, 1994; Li and Buckle, 1999; Wells et al., 1997; Winkel and Mathiassen, 1994). The hospital industry, subsuming the wide variety of occupations that are required to perform patient care and non-patient-related tasks, is notable for multiple potential sources of

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both physical and psychosocial stressors, providing a rich area for investigation to delineate risk more precisely.

Most studies involving hospitals have focused on patient-related tasks such as lifting and transferring by nurses and nursing assistants (Brown and Thomas, 2003; Collins and Owen, 1996; Engkvist et al., 1998; Engkvist et al., 2000; Evanoff et al., 1999, 2003; Feldstein et al., 1993; Geiger-Brown et al., 2004; Ostry et al., 2003; Trinkoff et al., 2003; Yassi et al., 2000; Yassi et al., 2001; Yassi et al., 1995). For those who perform patient-related functions, there is evidence that jobs or tasks with poor ergonomics characteristics not only result in higher levels of absenteeism and WRMSDs, but also may lead to lower levels of patient safety as well. This makes hospital workers an even more important group in which to study such ergonomics problems (Agency for Healthcare Research and Quality, 2003; Busse and Bridger, 1997; Larese and Fiorito, 1994). Patient acuity and dependence levels, nursing skill mix, and staffing levels can all add to the physical and psychosocial strain on health care providers (Aiken et al., 2003; Aiken et al., 2002).

These issues, among others, have led some organizations to undertake widespread "evidence-based" initiatives to improve the working conditions of healthcare workers (Yassi et al., 2002). Despite such initiatives, little effort has been expended in studying the full range of occupations necessary for the operation of this unique industry, especially those not involved in direct patient care, such as housekeeping, maintenance and food service workers.

2. Methods

2.1. General overview and study aims

This paper focuses on the design and implementation of observational techniques (i.e., on-site documentation of postures and activities) to directly assess physical risk factors for musculoskeletal injury among the full range of hospital workers at two large tertiary hospitals. In addition, we describe data collection methods designed to supplement these observations (e.g., self-reported and interviewer-obtained measures of physical stressors). In particular, we address the practical aspects of conducting assessments of the physical work environment in the hospital setting, given the complex nature of the tasks involved, the time and space constraints in such environments, and the privacy issues inherent in many clinical activities.

Thus the overall goal of this case study is to document the development and validation of an integrated approach to ergonomics assessment of occupational exposures across a range of hospital workers. We wished to put this in the context of the basic tools generally available to occupational researchers, while highlighting the specific aspects of the health care sector that affected our decision-making as we developed our hospital-based protocols. Specifically, we wished to describe and validate modifications we made to an existing ergonomics tool, Rapid Entire Body Assessment (REBA) schema (Hignett and McAtamney, 2000), by refining its weighting and scoring algorithms. We also tested the integration of additional elements into REBA format. These were added because they addressed sedentary tasks (including activities at laboratory and computer workstations), thus making our REBA adaptation more appropriate to the range of occupations encountered in hospital settings.

2.2. Study setting

The ergonomics assessment is one component of an ongoing longitudinal, case-control investigation, Gradients of Occupational Health in Hospital Workers (GROW) study. The GROW study is designed to follow cases of acute and cumulative WRMSDs of the trunk, neck, and upper and lower extremities among injured employees and to simultaneously follow a referent cohort of non-injured hospital workers. A summary of key study instruments and methodology, particularly details of the core structured questionnaire used and the qualitative study arm, have been previously reported. (Gordon et al., 2005; Rugulies et al., 2004).

The sampling strategy is designed to recruit employees from widely different economic groups performing a heterogeneous range of jobs with varying psychological and physical attributes. The ergonomics component, one part of a three-pronged investigation, provides a pivotal link between the psychosocial survey component of the study (interviewer-administered structured questionnaire) and an ethnographic exploration of the socio-cultural milieu of the study institutions. One of the more interesting opportunities provided by this study design is the ability to apply this analysis across a broad range of hospital jobs in the context of concomitant psychosocial risk factors identified through the other study components.

2.3. Subject recruitment

Eligible participants were recruited from a study base of approximately 6000 hospital workers at two institutional sites (including nurses and other health care professionals, technical workers, administrators, clerical, and skilled and unskilled craft workers; only physicians were excluded from the eligible participant pool). Cases are defined by occurrence of a new presentation of an on-the-job musculoskeletal injury (either acute or cumulative trauma), assessed by occupational health providers at each site's hospital-based employee health clinic. Once cases and referents (matched by job group, shift work status, or at random for a total ratio of controls: cases of 3:1) have been recruited, they are followed prospectively for a period of approximately 24 months.

2.4. Overview of the ergonomics component of GROW study

From an ergonomics perspective, GROW study goals include the direct observation of both cases (injured) and referent subjects while carrying out their normal work tasks. This approach was predicated on the assumption that a wide variety of different hospital-based occupations would be represented and that the observation periods would be relatively brief. Thus strategically, we wished to position ourselves to gather both individual-specific data that would assess within-person variability in activities over a discrete observation period, while also capturing variability among persons clustered by job-type. Because GROW study focuses on WRMDs, our ergonomics assessments needed to emphasize potential exposures related to these outcomes (as opposed to ergonomics factors associated with sharps injuries, for example). Tactically, we understood that our approach would need to be relatively unobtrusive, an issue that we will discuss at greater length in relation to the specific instrument choices made.

2.5. Measuring the physical workload on the job—general aspects (note: shortened greatly)

Physical load is typically assessed through the analysis of posture, movement, and peak force or cumulative load over time. Exposures can be complex, involving multiple spheres of activity such as lifting, pushing, grasping and the concomitant characteristics of these activities such as velocity, acceleration, frequency and duration (Burdorf and van der Beek, 1999a, b, c; Marras et al., 1999). Job evaluation techniques, although varied, all attempt to capture this complexity within a manageable construct. Consistent with this, physical workload has been measured indirectly (e.g., questionnaires, checklists, or diaries), quantified through instrumentation (e.g., goniometers, inclinometers), or estimated through direct observational methods. Our first task in formulating an ergonomics assessment strategy for GROW study was to assess the potential strengths and limitations linked to each of these three broad options of questionnaire administration, observation, or instrumentation.

Questionnaire data (typically based on self-report) are advantageous when precision and detail in measurement are not paramount, despite limitations in the methodology (Burdorf and van der Beek, 1999a, b, c; Kilbom, 1994; Li and Buckle, 1999). Such measures have not consistently correlated with direct observation in upper extremity assessment (Hansson et al., 2001). For example, in a study of office workers, self-reports of keyboard use were consistently higher than the results of objective keyboard monitoring and videotaping (Homan and Armstrong, 2003). Subjective data provided through questionnaire assessment can also be subject to systematic reporting bias (Andrews et al., 1998; Dehlin et al., 1976; Magora, 1970; Waters et al., 1993). In early studies, weak correlations were found between self-report and reference measurements (Wiktorin et al., 1993). As questions, protocols, and methodologies have been refined, however, better agreeement has been reported in some studies and for some postures and work tasks such as sitting, hands above shoulder level, and hands below knuckle level, allowing adequate application in the field under certain circumstances (Andrews et al., 1998; Balogh et al., 2001; Kilbom, 1994; Leijon et al., 2002; Li and Buckle, 1999; Mortimer et al., 1999; Wells et al., 1997; Wiktorin et al., 1996; Wiktorin et al., 1999).

Observational methods aimed at characterizing postures can be effective in dynamic work situations when it is necessary to assess multiple types of activity (Paquet et al., 2001). Simple observational checklists are best used for rapid, initial assessments, often dichotomized to a yes/no option. More elaborate observational systems that transcend dichotomous checklists can involve paper and pen notations or utilize computer assistance. Examples of these include Ovako Working Posture Analysing System (OWAS) (Kant et al., 1990, 1992; Louhevaara and Suurnakki, 1992), Rapid Upper Limb Assessment system (RULA) (McAtamney and Corlett, 1993), Posture, Activity, Tools, and Handling (PATH), (Buchholz et al., 1996; Paquet et al., 2001), and most relevant to GROW study, REBA (Hignett and McAtamney, 2000). The use of event-focused systems, such as OWAS, RULA or REBA, may present limitations when observing heterogeneous jobs, since they may not capture the range of activities more easily observed when using an activity or work-sampling method (Buchholz et al., 1996; Corlett et al., 1979; Paquet et al., 1997). Furthermore, if the activity observed is unusual, difficult to categorize, or simply missed, the risk factors may not be captured adequately.

Videotaping is often used in ergonomics analysis to capture postures and movements that may be difficult to record with direct observation. Drawbacks include the potential disruption of work, the cumbersome nature of setting up cameras in hospital workspaces, and the difficulty of following workers who perform non-stationary tasks. Even under optimal circumstances, videotaping provides only visible task and postural data and this technique is likely to be cumbersome and disruptive in hospital settings. Moreover, in the US in particular, the question of privacy in videotaping, both real and perceived, can become an overriding concern, especially in a patient care setting.

Instrumentation (for example, goniometers, inclinometers, or electromyography) allows direct measurement of joint angles, muscle loads and forces through use of electromechanical devices (Hansson et al., 2001; Kilbom, 1994). Particularly relevant to the hospital setting, the use of such methods is difficult when exposure to bodily fluids is anticipated or when frequent hand washing is necessary. In addition, the disruption of the work associated with attaching and calibrating such devices often limits their field application. Nevertheless, some studies of health care professionals and hospital workers have been carried out using electrogoniometers and electromyography (Akesson et al., 1997; Marras et al., 1999).

2.6. Construction of GROW ergonomics assessment tool

The previous summary identified methods of evaluating tasks and activities that were theoretically available to us in GROW study. Employing a multidisciplinary approach to weigh the advantages and disadvantages of various methods, we used an operating sub-committee who met at regular intervals to review, select, and adapt existing tools, similar to the process we used in questionnaire construction (Rugulies et al., 2004). One of the co-investigators (IJ), an ergonomist, took the lead in guiding the discussion with input from co-investigators representing the disciplines of epidemiology, medical anthropology, clinical occupational medicine and nursing, psychology, public health, and sociology. Other ergonomics team members also provided feedback regarding the usefulness and feasibility of observational techniques proposed by committee members.

Together, this consensus-building group refined and developed the instrument and study protocols choosing the least intrusive, most cost-effective, and most efficient methods of data collection for use in the complex health care milieu that we faced. The tools were selected using the following criteria: (1) appropriateness for use in patient care settings where confidentiality and privacy demand discretion and sensitivity; (2) adaptability to heterogeneous environments and effectiveness across a range of occupations where, even within a single job, a variety of tasks can occur during the course of any one observation period (e.g., patient care and clerical activities); and (3) a relatively narrow window of time for observation, given the range of tasks often performed.

First, the committee concurred that videographic observation would not be appropriate in our hospital environments. Video cameras were considered to be overly invasive and impractical for patient care situations. We considered this an insurmountable burden for purposes of obtaining informed consent in a number of situations. In that light, the epidemiological input from our multidisciplinary team voiced concern about introducing a selection bias if only certain, but not all, routine activities would be available for videotaping. As a secondary consideration, the plethora of medical equipment and devices used in clinical care, and movements of the employee and patient, might often obscure the visibility of the "target," a point affirmed by our clinicians. For similar practical reasons, we did not entertain an instrumentation-based approach to ergonomics assessment in this field study, given the number of subjects ($N > 600$) employed in diverse occupations, many of which involved direct patient care. In addition, instrumentation would not have been feasible nor approved by hospital management at either site, who had already determined that the study itself could be somewhat intrusive.

Given the rejection of videographic observation and instrumentation, the only viable remaining option was an observational approach. We recognized that a simple (i.e., dichotomous) checklist format would be insufficient. Early on, the consensus view held that an existing instrument (or instruments) would be preferable for application in GROW study. We gave primary consideration to three extensively tested instruments already noted above: OWAS (Louhevaara and Suurnakki, 1992), PATH (Buchholz et al., 1996); and REBA (Hignett and McAtamney, 2000).

Because of the importance of trunk and shoulder postures in hospital work, the treatment of these areas as dichotomous postural variables in OWAS was viewed as a serious limitation. Although PATH captures more postures, forces, and activities typical in non-cyclic and long-cycle work, we determined that the lack of a summary score generated by this instrument, such as might be included as a predictor in a multivariate model of injury risk or injury outcomes, made PATH less attractive as an analytic tool for GROW investigation. In addition, PATH instrument provided protocols for some activities not typical of hospital tasks (e.g., sitting on the ground), while, at the same time, it did not provide items for certain other activities likely to be important in the hospital industry (e.g., contact stress and wrist postures associated with computer or laboratory work).

The REBA (Hignett and McAtamney, 2000), which is based on RULA (Hignett and McAtamney, 2000; McAtamney and Corlett, 1993), adds items that capture data on leg positions and foot support while standing, and uses a similar scoring system to RULA. For these reasons we elected to conduct work sampling, as performed in PATH, but using REBA as a model data collection structure. In addition, we expanded this approach by supplementing REBA with an additional validated checklist focused on computer use (see below).

2.7. Rapid entire body assessment and supplemental items

The REBA (Hignett and McAtamney, 2000) provides a mechanism for recording postures of virtually all parts of the body, excluding the position of the foot and ankle. During the development of REBA, researchers found a 62–85% agreement on scoring various postural conditions, except for the upper arm category (Hignett and McAtamney, 2000). Moreover, REBA can record simultaneously occurring risk factors (i.e., static, repetitive, and awkward postures along with a categorization of forces exerted by the hands).

Although REBA (Hignett and McAtamney, 2000) has a number of advantages, it does not include several key components that we determined were necessary for adequately evaluating work in hospital settings, in particular tasks commonly associated with computer use and other office tasks. Although there are existing ergonomics survey instruments related to computer use, most office environment checklists are designed to assess workstation adjustability or the presence or absence of accessory products, for example, document holders (Bramlett, 1998). An alternative to this approach is to directly assess body postures; head, trunk, and extremity movements; and movement patterns when performing computer input or viewing and handling documents. Thus, rather than recording a description of workstation components, worker posture and movement patterns can be categorized and quantified.

Consistent with this approach, a 25-item checklist, the University of California (UC) Computer Use Checklist has been developed and validated (Janowitz et al., 2002). It is divided into four key areas of concern (work patterns, visual demands, upper extremity activity, and body posture and support), incorporating critical risk factors such as awkward postures, contact stress, and repetitive motion. The full checklist allows for a summary score, as well as multipliers that can be applied to address interactive effects between simultaneously occurring risk factors. We selected five of the items from this checklist to use in conjunction with REBA, capturing additional information on upper extremity and back support, mouse use, wrist extension between 15° and 22°, and sitting leg postures (see Appendix A for details). In addition, we expanded REBA concept of coupling to include awkward hand postures while performing computer input and using clinical and laboratory devices such as pipettes and intravenous equipment.

2.8. Sampling mode and new scoring algorithm

As noted previously, in order to capture the complex, heterogeneous nature of hospital tasks, we chose to apply REBA tool (Hignett and McAtamney, 2000) in a "work sampling mode," as opposed to using it as an event-based assessment completed once for each task of interest. During pilot testing, we found that we could record observations every 2 min, allowing for approximately 30 observations per hour. Activity sampling has been used for more than 60 years, and consistent with our approach, at least one other event-based system (OWAS) also has been adapted for use in a work sampling mode (Corlett et al., 1979; Jin et al., 2002; Neumann et al., 2001; Paquet et al., 2001). Although REBA is practical and convenient for postural analysis of work activities (Hignett and McAtamney, 2000), its scoring protocol has not been fully validated. To address this, we developed a scoring algorithm adaptable to REBA data collection structure and consistent with its items, yet taking into account a work sampling mode and heterogeneity of the tasks.

First, we posited that calculating scores for upper extremity and trunk/lower extremity postures might be more fruitful than an overall whole-body score as called for in REBA (Hignett and McAtamney, 2000). For example, in an overall score, high upper extremity exposures might be 'washed out' by low trunk or lower extremity scores. Second, from a purely biomechanical standpoint, we determined that the scoring system might be better served by combining the neck items with the shoulder and upper extremity, rather than combining it with the trunk, as occurs in REBA. Third, we integrated scoring derived from the additional items related to sedentary positions and computer tasks derived from the UC computer checklist as described previously. Finally, we applied a new weighting algorithm to postures, 'penalizing' extreme or unsupported postures with higher ratings, and modifying these with a 'protective' factor when indicated. For example, a flexed elbow with or without arm support is assigned a score of 1, but if contact stress were concurrently present, the score is increased to a value of 3. By contrast, the presence of distributed arm support would lower the score of an otherwise awkward upper extremity posture. Load interacting with posture comprises a key concept underlying our approach to scoring, in that it allows for multiplicative effects and represents a substantive departure from the original REBA algorithm (see Appendix B).

The revised scoring system we employed in GROW, based on the original constructs of REBA (Hignett and McAtamney, 2000), which in turn was developed from RULA (McAtamney and Corlett, 1993), will be referred to in this paper by two acronyms. The score for the neck and upper extremity is referred to as UBA-UC (Upper Body Assessment—University of California) and for the trunk, back, and lower extremity, as LBA-UC (Lower Body Assessment—University of California).

2.9. Duration of computer use and ergonomics self-assessment tools

We wanted to complement UBA-UC and LBA-UC with additional measures of ergonomics risk factors that also might be relevant to WRMSDs in our hospital cohort. First, we simply noted the total time spent on computer activities during the ergonomics observation. Second, we used this opportunity of direct contact with study participants to obtain a self-assessment measure, although we recognized that the correlation between self-report and observer-determined and/or interview-obtained assessment varies among studies (Leijon et al., 2002; Mortimer et al., 1999; Pope et al., 1998; Torgen et al., 1997; Viikari-Juntura et al., 1996; Wiktorin et al., 1993; Wiktorin et al., 1996).

For the self-assessment measure, we chose the Dortmunder questionnaire, a brief self-assessment for lifting and bending (Burdorf and van der Beek, 1999c; Hollmann et al., 1999; Jäger et al., 2000). This instrument has demonstrated acceptable test–retest reliability when used in a health care setting ($r = 0.65$), and has been shown to discriminate among occupations with differing physical work loads. In addition, physical load measured by this questionnaire demonstrated low to modest correlations with back, shoulder, and neck ($r = 0.21-0.35$) and distal symptoms ($r = 0.13-0.19$), and a statistically significant, albeit low, correlation with job satisfaction ($r = -0.05$ to -0.14). The Dortmunder instrument uses both text and pictograms in an easy-to-use self-report format, and calculates an Index for overall physical work load using the Dortmunder Biomechanical Model of the spine (Jäger et al., 2000). We modified this questionnaire by including pushing and pulling exertions, and explicitly defined postural break points consistent with those of the authors (Hollmann et al., 1999) (see Appendix C).

As a final measure, complementary to UBA-UC and LBA-UC, we also saw a need for peak load assessment. Daynard et al. (2001), Norman et al. (1998), and others have stressed the need to consider both cumulative and peak loads when analyzing patient handling and other activities that place high levels of stress on the spine over time. For this reason, in the context of ongoing study activities, we also intend to supplement the work sampling and self-report data described above by analyzing the highest forces reported by subjects with simulations that match the forces, postures, and other key parameters of these tasks. Further data on this approach will not be presented here.

2.10. Software development

To facilitate the field use of our observational instruments, we developed a computerized recording system, allowing the observer to carry out work sampling over time. Specifically, we used a personal digital assistant (PDA) for field data collection. Software was developed that allowed sequential recordings of job tasks using the combined ergonomics checklist items (Hignett and McAtamney, 2000; Janowitz et al., 2002), as well as basic safety and environmental observations (Lack, 1996). Most of the items were developed as multiple-choice selections using check boxes or drop-down menus. The software, however, was designed to allow the user to write in free form in preselected areas made possible by using a choice of handwriting recognition software or a "soft keyboard." Selected sample displays are illustrated in Appendix D. The instrument was pilot tested at two hospitals, not part of GROW study, allowing the evaluators to make adjustments to the protocol before use in the reported study.

At the beginning of the observation period, participants completed the Dortmunder self-assessment noted above. The evaluator entered this information on PDA along with subject information, such as gender, job title, location, and job task being performed. The PDA also functioned as a timer, notifying the observer when the next observation was due to be made. Each observation set was numbered on the screen; after each set of entries was saved, PDA progressed to the next observation screen.

2.11. Assessment training and inter-rater reliability testing

One of the co-investigators (IJ) provided training to the study field observer (GR). The training consisted of a review of the exposure assessment methods to be used, simultaneous observation of videotapes of workers performing relevant tasks at non-study sites, and simultaneous live observations of hospital workers at pilot test sites. The recordings of the field observer were reviewed after each session. On-site use of the study instruments was made by the field observer for at least 15 one-hour sessions before being permitted to conduct independent observations.

Two methods of inter-rater reliability (Dawson-Saunders and Trapp, 1994) were used to compare the results obtained by the field observer to those of the study ergonomist. The first method used videotaped presentations of representative tasks from non-study sites (patient care, housekeeping, and office work), both in 'freeze-frame' and moving video. The second method involved simultaneous live observation of study participants by the field observer and the study ergonomist. All observations were separately entered on a PDA, with each observer blinded to the other's ratings until the data were compiled on a desktop PC.

There were five subjects in the videotaped presentation, with a total of 118 observations: 70 from the still frames and 48 observations from the video segments played in real time. Four simultaneous live evaluations were conducted, with a total of 100 observations from each observer. Using Lin's Concordance Correlation (Lin, 1989), the overall correlation for all 218 pairs of observations was 0.53 for observations of the upper body and 0.66 for the lower body. The trunk/lower extremity correlations were fairly consistent for the videos (0.76), still frames (0.65), and live observations (0.62). The upper quadrant score correlation was higher for the videos (0.68) than for the still frames (0.37) and the live observations (0.36).

Dividing each score into quintiles, the overall Kappa was 0.54 for the upper quadrant score and 0.66 for the trunk/lower extremity score, weighted to account for the degree of differences between the two observers (Fleiss and Cohen, 1973). According to the classification system for Kappa scores proposed by Landis and Koch (1977), this represents "substantial" agreement overall ('fair' scores fall between 0.20 and 0.40; <0.20 represents 'poor' or 'slight' agreement). Fig. 1 illustrates the inter-rater reliability for each individual item (each is listed on the horizontal axis in order of descending Kappa score). Of the seven items scoring less than 0.40, all but one were related to the distal upper extremity. Only one of the items, left wrist position, yielded a Kappa less than 0.20. In a prior study, all items from the UC Computer Use Checklist (Janowitz et al., 2002) had Kappa scores of at least 0.40; the difference may be explained by the inclusion of more dynamic tasks in the present study, as opposed to more heterogeneous office jobs evaluated previously. A study of truck drivers and trash collection (Massaccesi et al., 2003) found that RULA predicted neck and trunk symptoms well, but the correlation with upper extremity symptoms was poor. We modified the wrist extension categories to allow for a "middle zone" of 15–22°, but further testing may allow for the development of break points that lead to higher inter-rater reliability.

2.12. UBA-UC and LBA-UC performance characteristics

A total of 664 subjects completed the baseline structured questionnaire arm of GROW study; 497 (75%) underwent ergonomics observations. Of these, there were 494 subjects for whom there were an adequate number of 2-min time point assessments, thus yielding summary data for a total

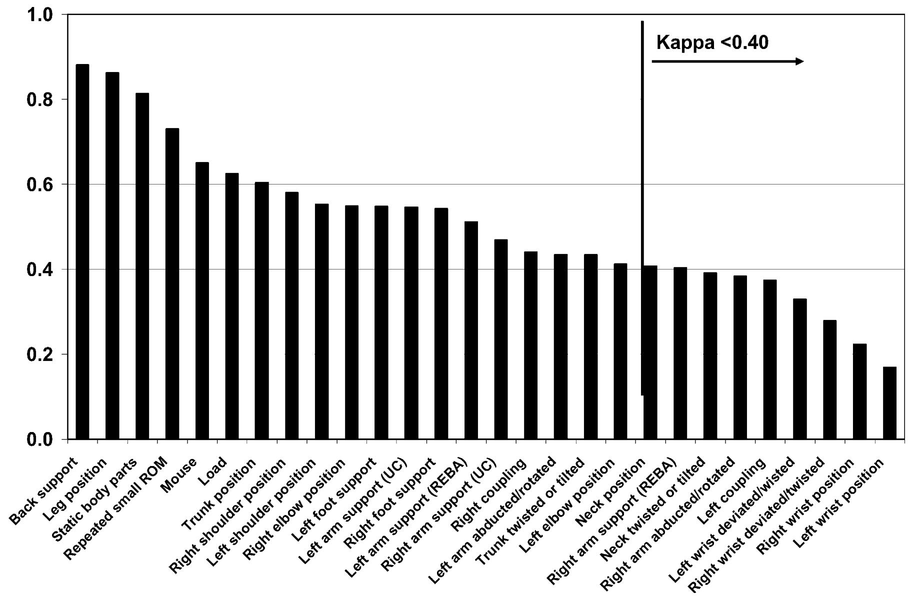

Fig. 1. Kappa statistic for each REBA (Hignett and McAtamney, 2000) item arranged in descending order.

Table 1
Components of UBA-UC and LBA-UC ergonomics scoring ($N = 14{,}404$ observations; 494 subjects)

Component		Mean	90th percentile	Observed range
Number of observations per person		29	32	16–42
Upper body				
Upper extremity measures				
Shoulder	Left	0.63	4	−1 to 28
	Right	0.81	4	−1 to 28
Elbow	Left	0.42	2	0–4
	Right	0.38	2	0–4
Wrist	Left	1.82	3	0–7
	Right	2.07	5	0–7
Coupling	Left	0.87	1	0–15
	Right	0.95	1	0–15
Arm support	Left	0.63	3	−3 to 3
	Right	0.58	3	−3 to 3
Upper extremity, maximum right or left		5.34	10	−4 to 49[b]
Mouse		0.18	0	0–2
Small ROM[a] movement		2.16	3	0 or 3
Neck		1.52	5	0–5
Upper quadrant score		9.19	16	−4 to 56[b]
Trunk/lower extremities				
Trunk		1.27	4	−3 to 36[b]
Legs		0.36	1	−2 to 3
Knees, if standing		0.24	0	0–15
Sitting position of legs		0.24	2	0–2
Foot support		0.14	0	0–5
Static position for > 1 minute		3.75	5	0 or 5
Large postural changes with an unstable base		0.23	0	0 or 8
Trunk/lower extremity score		6.23	10	−3 to 52[b]

[a]ROM, range of motion.

[b]For these scores, the possible range differs from the observed range as follows: Upper extremity score, −4 to 57. Upper quadrant score, −4 to 67. Trunk score, −4 to 72. Trunk/lower extremity score, −4 to 103. Some high values would result from extremely awkward or improbable body postures. See Appendix 2 for details on scoring.

of 14,404 separate time-point observations available for detailed analysis. As shown in Table 1, UBA-UC and LBA-UC scores have comparable scales and observed ranges. For both the upper and lower extremities, the theoretical upper range scores were not achieved, suggesting that very extreme postures and very high loads are unlikely to occur simultaneously in this work setting.

Table 2 shows the correlation among the observational scores as calculated using the original REBA algorithm, the separate UBA-UC and LBA-UC scores that we developed for this study, and, for each, the amount of time spent in "high strain" postures. For REBA, this has been defined previously as a score $\geqslant 8$ (Hignett and McAtamney, 2000). For UBA-UC and LBA-UC, we defined this as a score equal to or greater than the 90th percentile based on all observations of all subjects ($n = 14,404$, as noted above). In addition, Table 2 also provides the correlations for two other measures: the modified Dortmunder Index of Physical Load and the percent time during the observation spent on computer activities, a measure of exposure not captured by the items selected for UBA-UC.

Both UBA-UC and LBA-UC correlate significantly with REBA. The high strain observations correlate somewhat less strongly, although in all cases these also are statistically significant. Moreover, the correlations between UBA-UC and LBA-UC indicate that they are interrelated, but not redundant (that is, wholly overlapping) measures.

The modified Dortmunder Index has a modest correlation with LBA-UC, but it is not correlated with UBA-UC, supporting the validity of the upper and lower segregation of scores. It is interesting to note that the percent time on computer tasks did not correlate with either UBA-UC or LBA-UC, supporting our assessment that this exposure is operating independently from either position-load measure, and indeed correlates negatively with extreme position loads.

For all of the measures analyzed, there was statistically significant variation by occupational group (see Table 3). On the basis of the relative rankings of the groups, a number of relevant observations can be made. The largest occupational category by number (Nurses; $n = 178$) ranked consistently third among the six groups studied for UBA-UC and LBA-UC (both for average and high-strain positions) and ranked second on the Dortmunder scale. In contrast, based on the original REBA algorithm, nurses ranked lowest, tied with "other clinical occupations". Administrators, whom we anticipated would rank lowest relative to the other groups, did indeed rank either fifth or sixth on UBA-UC, LBA-UC, and the Dortmunder Index. The percent time spent on computer tasks was particularly notable for this group, consistent with face validity. In contrast, the total REBA score did not differentiate administrators from "technical" positions and, overall, placed this group as ranking higher (that is, in the direction of greater ergonomics risk) than both nurses and "other clinical positions". At the other extreme, "support" staff (e.g., housekeeper, food service worker, physical plant operators, and supply and distribution personnel) ranked the highest in relative terms by each of the measures, except for time spent on computer use, by which measure they ranked lowest.

With regard to the amount of time spent in "high strain" postures, (i.e., at or above the 90th percentile score), there was a statistically significant difference among the

Table 2
Correlation matrix for 14,404 ergonomics measures obtained from observations among 494 subjects

Ergonomic measurement type and frequency					Corelation matrix among measurements					
Ergonomics measures		Mean (SD)	REBA average	REBA high strain	UBA-UC average	UBA-UC high strain	LBA-UC average	LBA-UC high strain	% Time on computer	Dortmunder Index
REBA ($N = 494$)	Average individual score	5.3 (1.2)	1.0							
	Percent time, high strain postures	17.0 (17.5)	0.79*	1.0						
UBA-UC ($N = 494$)	Average individual score	9.1 (3.0)	0.67*	0.64*	1.0					
	Percent time, high strain postures	9.7 (14.5)	0.49*	0.62*	0.77*	1.0				
LBA-UC ($N = 494$)	Average individual score	6.2 (2.2)	0.48*	0.52*	0.36*	0.38*	1.0			
	Percent time, high strain postures	10.6 (14.0)	0.29*	0.47*	0.35*	0.47*	0.66*	1.0		
COMPUTER TIME ($N = 494$)	Percent time spent on computer	24.3 (29.0)	0.25*	−0.01	0.08	−0.17*	−0.09***	−0.24*	1.0	
MODIFIED DORTMUNDER INDEX ($N = 350$)	Self-assessment score	18.1 (12.9)	−0.19*	−0.00	0.02	0.20*	0.16**	0.30*	−0.41*	1.0

*$p < .001$; **$p < .01$; ***$p = 0.05$.
REBA, Rapid Entire Body Assessment; UBA-UC, Upper Body Assessment—University of California (UC); LBA-UC, Lower Body Assessment—UC. High strain postures defined in REBA as a score $\geqslant 8$; High strain postures in the UC scoring system are defined as percent of observations for each individual subject for which the score was at or above the 90th percentile for all such scores among *all* observations ($n = 14404$) (See Methods).
For REBA and UC scores, the average score for each individual is the arithmetic mean summarized across all observations for that subject. The percent time on computer is based on the ergonomic observation record of the tasks performed at each observation, summarized across each subject.

Table 3
Variation in ergonomics measures by occupational group

Ergonomics score	Administrators ($n = 62$) Mean (SD)	Nurses ($n = 178$) Mean (SD)	Other clinical positions ($n = 69$) Mean (SD)	Technical positions ($n = 44$) Mean (SD)	Clerical positions ($n = 107$) Mean (S.D.)	Support positions ($n = 33$) Mean (SD)	ANOVA F-test	ANOVA p value
REBA								
Average individual score	5.5 (1.1)	5.1 (1.1)	5.1 (1.3)	5.5 (1.6)	5.6 (1.0)	5.8 (1.4)	4.79	<0.001
High strain postures (% time spent in)	13.8 (18.3)	16.1 (14.9)	16.8 (18.7)	23.0 (20.9)	15.4 (16.9)	25.2 (20.1)	3.23	0.007
UBA-UC								
Average individual score	8.7 (1.8)	9.0 (2.8)	8.3 (2.9)	10.2 (3.6)	8.8 (2.5)	11.8 (4.9)	8.28	<.0001
High strain postures (% times spent in	4.0 (6.4)	11.3 (13.7)	7.6 (12.8)	14.7 (18.5)	5.2 (9.6)	24.3 (24.3)	14.04	<.0001
LBA-UC								
Average individual scores	5.9 (2.3)	6.6 (1.6)	6.0 (2.1)	6.7 (2.1)	5.3 (2.2)	7.3 (3.5)	8.30	<.0001
High strain postures (% time spent in)	6.3 (10.6)	11.9 (13.1)	11.5 (13.8)	12.1 (15.0)	4.9 (8.6)	26.4 (21.8)	15.72	<.0001
COMPUTER TIME								
Percent time on computer	54.1 (29.3)	12.2 (19.1)	13.7 (23.2)	18.3 (22.0)	42.4 (29.9)	5.3 (16.1)	48.19	<.0001
MODIFIED DORTMUNDER INDEX								
Dortmunder index	11.2 (7.9)	23.2 (12.4)	16.8 (11.9)	19.9 (12.3)	10.4 (9.7)	32.7 (15.0)	21.03	<.0001

REBA, Rapid Entire Body Assessment; UC, University of California; UBA-UC, Upper Body Assessment—University of California; LBA-UC, Lower Body Assessment—University of California.

occupational groups for both UBA-UC and LBA-UC (UBA-UC: ANOVA $F = 14.09$, $p < 0.001$; LBA-UC: $F = 16.12$, $p < 0.001$). The percent time spent in high strain postures for both clinical positions (5%) and administrators (4%) was low, even taking into account the computer check list-derived measures included, highlighting an area for potential algorithm scoring refinement.

3. Discussion and summary

In this case study, we have reported the development of an observational approach to ergonomics assessment for various jobs within a hospital setting. We have delineated the limitations of this particular environment insofar as they drive the feasible field observation approaches that can be applied to the heterogeneous range of work tasks likely to be encountered there. Capturing such ergonomic data inevitably involves a compromise between detail and precision on the one hand, and the ability to adequately and efficiently sample heterogeneous work tasks on the other, especially in settings where most jobs are not stationary.

Specifically, we document the development and validation of a revised scoring algorithm based on the event-focused assessments in REBA (Hignett and McAtamney, 2000) and the UC Computer Use constructs (Janowitz et al., 2002). This revised scoring system separates upper and lower body positions and loads and weights them based on our understanding of the associated biomechanical effects. In this case study, we have shown that this new method performs well and differentiates among job groupings. We also show that an additional domain of time spent on computer tasks appears to capture an independent measure of job exposure.

We have attempted to build on the work of others in job analysis to fashion instruments to better enable us to study the physical demands of the wide range of tasks performed in hospitals. We intend to apply these new measures in a cross-sectional and prospective analysis of WRMDs and outcomes in the hospital setting. We believe that this assessment methodology could be applied in other research settings where large-scale observations are necessary to record ergonomics risk factors and job tasks in complex environments.

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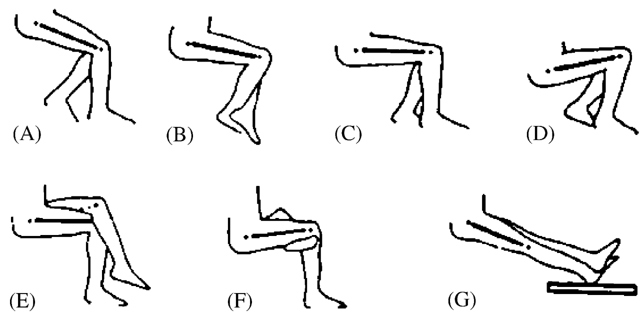
Appendix A. Additions from the University of California Computer Use Checklist (Janowitz et al., 2002)

1. The REBA options for wrist extension were modified by the addition of a category for flexion/extension between 15° and 22°.
2. Contact stress at the wrist or elbow is recorded if the elbow is resting against a hard surface or one that is less than 2 inches wide, and the location(s) of upper extremity support (wrist, forearm, elbow) is noted.
3. The use and location (right vs. left) of pointing devices are recorded if applicable.
4. The presence and location(s) of back and/or neck support when sitting.
5. If the subject is sitting, an item from the UC Computer Use Checklist is used to capture hip and leg position:



Appendix B. GROW ergonomics scoring algorithm

B.1. Upper Body Assessment (UBA-UC)

1. Upper Extremities, scored separately for right and left extremity.
   a. Shoulder

Basic position	Points	Arm support
Extension <20° or Flexion 0–20°	0	−1
Flexion 20–45°	2	−2
Extension >20° or Flexion 45–90°	4	−3
Flexion >90°	7	−5

Add 2 points for abduction/rotation, prior to calculating effect of load.
Multiply score by 1.5 for loads 11–22 lbs., by 3.0 for loads >22 lbs.
(Minimum effect of load is 1 point, regardless of baseline score.)
Add 1 point if shoulders raised.

Shoulder score range:
Minimum score (−1): Neutral position, no load, with arm support.
Maximum score (28): Flexion >90, abducted or rotated, >22 lbs. load, raised shoulders, no arm support.

   b. Elbow

Basic position	Arm support	Points
Flexion 60–100°	With or without	0
Flexion <60°	With	0
Flexion >100°	With or without	1
Flexion <60°	Without	2

Add 2 points for contact stress (CS).

Elbow score range:
Minimum score (0): Moderate flexion without CS, or minimal flexion with support and no CS.
Maximum socore (4): Minimum flexion with CS and without support.

c. Wrist

Basic position	Points
Flexion/Extension 0–15°	0
Flexion/Extension 15–22°	1
Flexion/Extension >22°	3

Add 2 points each for contact stress or deviated/twisted position.

Wrist score range:
Minimum score (0): Neutral position, without contact stress, deviation, or twisting.
Maximum score (7): Maximum flexion/extension, with contact stress, deviation, and twisting.

d. Coupling

Basic position	Points
Good	0
Fair	1
Poor	3
Unacceptable	5

Multiply score by 2 for loads 11–22 lbs., by 3 for loads >22 lbs.
(Minimum effect of load is 1 point, regardless of baseline score.)

Coupling score range:
Minimum score (0): Good grip, no load.
Maximum score (7): Unacceptable grip, load >22 lbs.

e. Arm support

Joints supported	Points
Wrist, forearm, elbow	−3
Forearm only	−2
Forearm with wrist or elbow	−1
None	0
Wrist, elbow	2
Elbow or wrist alone	3

Arm support score range:
Minimum score (−3): Full arm support.
Maximum score (3): Elbow or wrist alone.
Upper Extremity score = Shoulder + Elbow + Wrist + Coupling + Arm Support.
(Maximum of left and right side scores.)
Total possible range: −4 to 57.

2. Neck

Basic position	Points	Rotation/lateral flexion
Flexion 0–20	0	+1
Any extension or flexion >20°	2	+3

Neck score range:
Minimum score (0): Minimal flexion, no rotation or lateral flexion.
Maximum score (5): Flexion or extension, plus rotation or lateral flexion.

3. Small range of motion (ROM) movements (>4/ minute): +3 points.
4. Mouse: +1 point for left-handed use, +2 points for right-handed.
Upper Quadrant Score: Upper Extremity + Neck + Small ROM + Mouse.
Possible range: −4 to 67.

B.2. Lower body assessment (LBA-UC)

1. Trunk
   a. Standing

Basic position	Points	Rotation/lateral flexion
Upright	0	+1
Extension or flexion 0–20°	1	+1
Extension >20° or flexion 20–60°	3	+3
Flexion >60°	6	+6

Multiply score by 2 for rapid build-up or shock.
Multiply score by 1.5 for loads 11–22 lbs., by 3.0 for loads >22 lbs.

   b. Sitting

Basic position	Points	Rotation/lateral flexion
Upright	1	+1
Leaning forward or backward	2	+2
Slouching forward or backward	3	+3

Multiply score by 1.5 for loads 11–22 lbs., by 3.0 for loads >22 lbs.
Sitting support (add up all points of support)

Point of support	Points	Point of support	Points
Cervical	−1	Lumbar	−1
Thoracic	−1	Sacrum	−1

Trunk score range:
Minimum score (−4): Sitting upright, no rotation/lateral flexion, no load, full back support.
Maximum score (72): Standing, maximum flexion, load >22 lbs., with rotation or lateral flexion and rapid buildup or shock.

2. Lower extremities
   a. Legs

Position	Points	Position	Points
Walking	−2	Bilateral weight bearing	2
Sitting	0	Unilateral weight bearing or unstable position	3
Standing	1		

   b. Knees, if standing

Basic position	Points
Flexion 0–30°	0
Flexion 30–60°	2
Flexion >60°	5

Multiply score by 2 for loads 11–22 lbs., by 3.0 for loads >22 lbs.
(Minimum effect of load is 1 point, regardless of baseline score.)

Knee score range:
Minimum score (0): Minimal flexion, no load.
Maximum score (15): Flexion >60°, load >22 lbs.

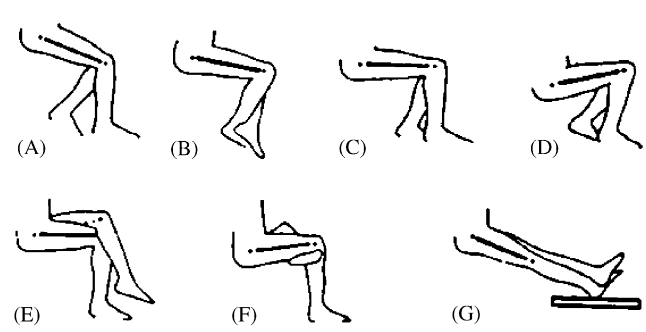
   c. Foot support, if sitting

Position	Points
Floor	0
Footrest	1
Chair base	3
Nothing	5

Average right and left foot position, if different.

   d. Leg position while seated

Position (see figure)	Points
C	0
A, E, G	1
B, D, F	2



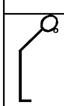
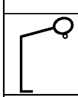
3. One or more body parts static for >1 min (static): +5.
4. Rapid large changes in position or an unstable base (rapid): +8.

Trunk/lower extremity score = trunk + legs + knees + foot support + leg position + static + rapid.
Possible range: −4 to 103.
(Note: a score of 103 would represent a severe strain on the lower back, due to the combination of posture, load, and force).

Appendix C. Self-report form based on the Dortmunder model, modified from Klimmer and Hollmann (Hollmann et al., 1999)

Please estimate how often you have to work in the body positions below, and how often you have to lift, push, pull or carry the weights indicated:

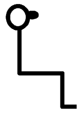
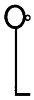
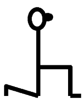
Trunk Posture

		never	seldom	sometimes	often	very often
	Straight upright					
	Bent half-way forward (about 45°)					
	Bent very forward (about 75°)					
	Twisted/rotated					
	Bent to the side					

Arm Position

		never	seldom	sometimes	often	very often
	Both arms raised so that elbows are above chin height					
	One arm raised so that elbow is above chin height					
	Both arms raised so that elbows are above chest height					
	One arm raised so that elbow is above chest height					
	Both elbows below chest height					

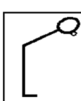
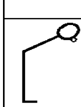
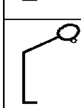
Leg Position

		never	seldom	sometimes	often	very often
	Sitting					
	Standing					
	Squatting					
	Kneeling (on one or both knees)					
	Walking, moving					

Lifting pushing, pulling or carry with upright trunk posture

		never	seldom	sometimes	often	very often
	Light force (up to 25 lbs.)					
	Moderate force (25-50 lbs.)					
	Heavy/high force (more than 50 lbs.)					

Lifting, pushing, pulling or carry with bent trunk

		never	seldom	sometimes	often	very often
	Light weight or force (up to 25 lbs.)					
	Moderate weight or force (25-50 lbs.)					
	Heavy weight or force (more than 50 lbs.)					

Appendix D. Sample PDA display screens

Figs. A and B display screens involving safety conditions and neck, trunk, and shoulder posture for a subject working in an intensive care setting using a syringe.

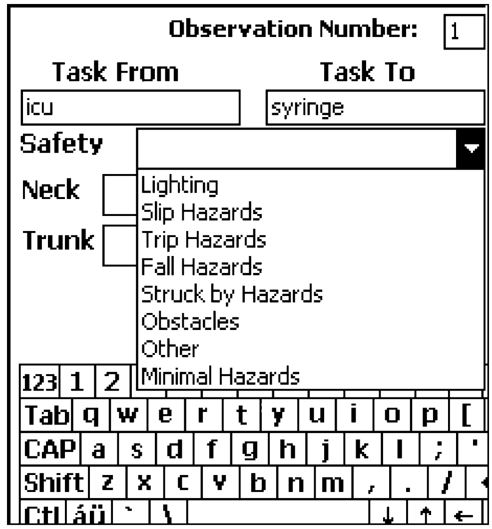


Figure A Safety Conditions

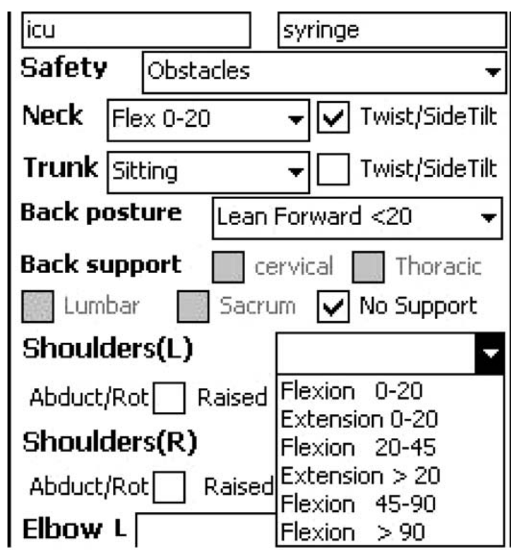


Figure B Upper Body Posture

In Fig. B, the flexion/extension angle of the neck and the trunk are each defined relative to vertical in the sagittal plane. Selections of twisted or tilted positions for both the neck and trunk are possible. The shoulder position is defined by the angle the humerus makes with the vertical. Additional observations of shoulder positions such as abduction, rotation, and raised shoulder (shrugging), can also be recorded as in REBA protocol.

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