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A randomized and controlled trial of a participative ergonomics intervention to reduce injuries associated with manual tasks: physical risk and legislative compliance

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A participative ergonomics approach to reducing injuries associated with manual tasks is widely promoted; however only limited evidence from uncontrolled trials has been available to support the efficacy of such an approach. This paper reports on a randomized and controlled trial of PErforM, a participative ergonomics intervention designed to reduce the risks of injury associated with manual tasks. One hundred and seventeen small to medium sized food, construction, and health workplaces were audited by government inspectors using a manual tasks risk assessment tool (ManTRA). Forty-eight volunteer workplaces were then randomly assigned to Experimental and Control groups with the Experimental group receiving the PErforM program. Inspectors audited the workplaces again, 9 months following the intervention. The results showed a significant decrease in estimates of manual task risk and suggested better legal compliance in the Experimental group.

1. Introduction

Musculoskeletal injuries related to the performance of manual tasks have been recognized as a source of significant pain, disability and disadvantage for the injured person and a substantial burden on modern societies. Statistics across a range of jurisdictions suggest that more than 30% of all occupational injuries are musculoskeletal injuries associated with manual tasks (e.g. NOHSC 1998, Liberty Mutual 2002).

One approach to reducing the burden from musculoskeletal injuries is participative ergonomics. Participative ergonomics developed from quality circles in Japan (Noro 1991, 1999), industrial democracy and social participation in Europe and Scandinavia (Jensen 1997, 2001), and the failure of traditional corporate control models to bring economic growth to US companies in the 1970s (Brown 1990, 1993). Whilst there are many variations in the models and techniques used in participative ergonomics (see Haines and Wilson 1998 for a review), the basic concept is to involve

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workers in improving their workplaces to reduce injury and increase productivity. In this way the expert knowledge workers have of their own tasks is utilized to assist in risk assessment and control.

Potential benefits of participative ergonomics are thought to include an improved flow of useful information within an organization, an improvement in the meaningfulness of work, more rapid technological and organizational change, enhanced performance and reductions in work related health problems (Brown 1993, Haims and Carayon 1998). Participative ergonomics has been used to create more human centred work (Imada 2000), to improve work organizational climate (Maciel 1998), to reduce mental workload (Vink *et al.* 1995) and to rehabilitate workers with back pain (Loisel *et al.* 2001).

Participative ergonomics has also been used to try to prevent musculoskeletal disorders associated with manual tasks across a range of industries including electrical manufacturing (St-Vincent *et al.* 1998), car manufacturing (Halpern and Dawson 1997), meat processing (NIOSH 1994, Moore and Garg 1997), print media (Rosecrance and Cook 2000), office computer work (Westlander *et al.* 1995), construction (Vink *et al.* 1997, de Jong and Vink 2000) and health (Straker 1990); and it is now the internationally recommended approach for reducing musculoskeletal diorders associated with manual tasks (Jensen 1997, NIOSH 1997, DOL 1999, Carrivick *et al.* 2001, Stubbs 2002). Despite this, there is only limited evidence to support the efficacy of such an approach.

1.1. *Evidence for the efficacy of participatory ergonomics*

Many uncontrolled case studies of participative ergonomics have been reported, with some showing improvements in health outcomes. For example, Koda *et al.* (1997) reported an increase in risk control actions and a decrease in compensable back pain incidence in an uncontrolled trial in the Tokyo waste disposal organization. Conversely some case studies have found a deterioration in health outcomes following a participative ergonomics intervention. For example, Moore and Garg (1997) reported an increase in musculoskeletal disorder incidence rate and lost time incidence rate in an uncontrolled trial in a meat processing plant. (Their later paper [Moore and Garg 1998] reported a marked decrease in lost time incidence rate.) However the absence of a comparison group means that the cause of any changes found in these and similar studies may not have been due to the intervention alone.

Wickstrom (1988) and Wickstrom *et al.* (1993) conducted a more strongly designed study in the metal fabrication industry in Finland. A participative ergonomics intervention was delivered in one factory, with a similar factory acting as a comparison. This eliminated some confounding factors, such as the impact of general economic conditions over time. A decrease in back pain in the intervention factory was reported, while no change was observed in the comparison factory.

A study with even better control was reported recently by Carrivick *et al.* (2001, 2002). This study involved an intervention for cleaners in one hospital in Australia and compared outcomes with orderlies in the same hospital, cleaners in a nearby comparable hospital, and cleaners in the whole of Western Australia. The intervention group experienced substantial reductions in injury rate, injury duration and injury costs, compared to increases in the comparison groups.

The Wickstrom *et al.* (1993) and Carrivick *et al.* (2001, 2002) studies provide reasonable levels of evidence for the efficacy of participative ergonomics to improve musculoskeletal injury outcomes. However, as the intervention and comparison groups were not randomly assigned, confounding factors may have caused observed differences. This limitation in the available evidence has impeded the implementation of participative ergonomics at an organizational level and at a government level (e.g. the difficulties associated with the introduction of an ergonomics standard in the USA). Randomized and controlled trials are recognized as the highest level of evidence (Sackett *et al*. 1997). Whilst the need for randomized and controlled trials in ergonomics has been recognized (Straker *et al*. 2001), only two such trials of participative ergonomics interventions have been reported.

Morken *et al*. (2002) recently reported on a randomized and controlled trial in the Norwegian aluminium industry evaluating worker vs. supervisor and manager training forms of participative ergonomics. Employees from eight plants were involved with supervisors and managers only, whole work teams, or work teams without their supervisors, in two departments assigned to participative ergonomics training or no training. Within the intervention groups, some groups had the supervisor only trained whilst others had the whole work team trained. Control work teams were on different shifts but were aware of the study and were consulted about control changes. Other departments in the plants formed a secondary non-randomized control group. The authors reported an increase in coping strategies in the intervention group but no changes in job control or musculoskeletal symptoms.

Earlier, Loisel *et al*. (1997) reported on a randomized and controlled trial using participative ergonomics to return people with back pain to their work. They found that the use of a group (including ergonomist, injured worker, supervisor and management and union representatives) to evaluate and generate solutions to hazards in the injured worker's worksite resulted in a more rapid return to full work duties than medical management.

No randomized and controlled trial of any participative ergonomics approach to reduce injuries at a workplace level has previously been reported. This is at least partly due to the resource and logistic difficulties in mounting a randomized and controlled trial involving multiple organizations (Straker 2000a).

1.2. *Measures of participative ergonomics efficacy*

Studies attempting to evaluate the efficacy of participative ergonomics interventions to reduce musculoskeletal disorders have used a plethora of outcome measures ranging from ratings of efficacy by a participative ergonomics committee (Rosecrance and Cook 2000), through physical measures such as heart rate (Pohjonen *et al*. 1998), to productivity measures (Maciel 1998) and cost-benefit analysis (Lanoie and Tavenas 1996).

Straker (2000b) classified the possible measures as either short or long term. Short term measures included measures of procedural activity, physical risk measures and psychosocial measures. Long term measures included productivity and health outcomes.

Procedural measures could include direct risk assessment and control activities as well as more indirect activities such as the development of appropriate management systems and policies. Physical risk measures could include observational ratings, physical measurement of hazards (e.g. weight of box), measurement of biological responses (e.g. heart rate) and estimates of biological stresses (e.g. low back moment). Psychosocial measures could include ratings by individuals of their discomfort, exertion, workload and satisfaction and estimates of the organizational environment such as safety culture and team cohesion.

Productivity measures could include work unit output, product quality/failure rate, system down time, and absenteeism. Efficacy has also been evaluated using cost-benefit analysis. Long-term health outcomes commonly used include musculoskeletal injury incidence rates, durations and associated costs.

The limitations of the various measures have been discussed previously (see Straker 1991, Burdorf 1992, 2000b, Li and Buckle 1999a,b) and it is clear that no single measure is adequate.

1.3. *Aim of research*

The aim of the current research was to evaluate the efficacy of a participative ergonomics intervention aimed at reducing injuries associated with manual tasks through a randomized and controlled trial using a battery of outcome measures. This paper describes the physical risk estimates and legislative compliance outcome measures obtained for randomly allocated Experimental and Control groups. The project also evaluated procedural activity, organizational environment, productivity and workers' compensation outcomes and used a qualitative research approach to investigate the process of implementing a participative approach: these aspects will be reported elsewhere.

2. Method

2.1. *Design*

A randomized and controlled trial was conducted to evaluate the efficacy, in terms of a range of outcome measures, of a participative ergonomics intervention aimed at reducing injuries associated with manual tasks in small to medium sized workplaces in three diverse industry sectors. An initial manual task audit of 117 randomly selected workplaces was undertaken by government inspectors between October and December 2000. These workplaces were invited to participate in the evaluation of the intervention, and 48 workplaces volunteered. Thirty-one of these workplaces were randomly assigned to the Experimental group and the remainder formed a Control group. Workplaces in the Experimental group received the intervention between March and July 2001. All workplaces, and an additional 30 similar workplaces which were not audited initially, were again audited between April and July 2002. The intervention was made available to Control workplaces in August to December 2002. This paper reports data obtained from the volunteer workplaces only (Experimental and Control).

2.2. *Sample*

Queensland is a large state in the North-East of Australia, covering 1.7 million km^2, with a population of 3.5 million people. The South-East corner of the state is relatively densely populated, with 65% of the population (2.3 million people) in an area equal to 1.3% of the state (22,339 km^2).

Workplace health and safety legislation in Australia is largely a State government responsibility, and the relevant authority in Queensland is the Division of Workplace Health and Safety in the Department of Industrial Relations. This authority maintains a database of all workplaces in the State, and inspectors employed by the authority have right of entry to inspect any workplace, without notice, to assess compliance with the Workplace Health and Safety Act (DIR 2000). Under the Act, workplaces employing 30 or more staff are required to manage the risk associated with manual tasks and to have a Workplace Health and Safety Officer, and must establish a health and safety committee. To assist employers to meet their obligations under the Act, the Department provides advisory standards, including a Manual Tasks Advisory Standard enacted in February 2000 (DWHS 2000). The Advisory Standard also advocates a consultative, participatory approach to risk assessment and control as the main approach to reducing associated musculoskeletal injuries.

The workplaces chosen for the initial audit employed 30–100 employees, were single workplace employers (i.e. not part of a larger organization) which were located within South-East Queensland and in one of three industry sectors. Small to medium-sized workplaces were chosen as these have been identified as an area of need because they employ a large proportion of the workforce yet have limited ability to provide in-house ergonomics expertise. Independent organizations were required so the workplace management could make decisions not constrained by remote, higher level management.

The industry sectors were chosen in consultation with Division of Workplace Health and Safety staff after a review of relevant compensation statistics. The workplaces chosen for initial audit conducted business in: food processing other than meat (Australia and New Zealand Standard Industry Classification (ANZSIC) (ABS 1993) codes 2112–2190), construction related manufacturing and wholesaling (ANZSIC 2323, 2741, 2742, 4531, and 4539), or health and community services, specifically nursing homes and accommodation for the aged (ANZSIC 8613 and 8721). For the sake of brevity, the industry sectors are hereafter referred to as 'Food', 'Construction' and 'Health'.

2.3. *Procedure*

Following identification of all workplaces which met the inclusion criteria ($n = 162$), 120 workplaces were randomly selected for initial audit. Three workplaces were not able to be audited due to closure or some other reason. Seventeen government Workplace Health and Safety inspectors were trained by the investigators in the use of a Manual Tasks Risk Assessment tool (ManTRA) which incorporates assessment of manual task risk levels, manual tasks related safety activity, and organizational environment (further details of which are provided in the following section). The Queensland government publicized that their inspectors would be conducting a 'blitz' on manual tasks, following the release of a revised Manual Tasks Advisory Standard in February 2000 (DWHS 2000). As required by the Workplace Health and Safety Act, where inspectors observed instances of a task which in the opinion of the inspector posed a significant risk of injury, the inspector was required to take action. This enforcement action involved one of the following actions: (i) issuing a prohibition notice which mandates immediate cessation of performance of the task; (ii) issuing an improvement notice which requires the employer to comply with the details of the notice within a given time frame; or (iii) providing formal written advice regarding the nature of the risk.

Following the initial audit, all audited workplaces ($n = 117$) were offered the opportunity to participate in the evaluation of a participative ergonomics intervention aimed at reducing injury risks associated with manual tasks. Forty-eight workplaces volunteered and 31 of these workplaces were randomly assigned to the Experimental group. The remaining 17 workplaces formed the Control group. Workplaces allocated to the Control group were informed that, due to the design of the evaluation, their participation would be delayed until the following year. Due to project timing constraints, random allocation of volunteers was initially weighted towards the Experimental group. The expected number of volunteer workplaces did not eventuate and consequently the Control group was smaller than planned. Table 1 provides a summary of the breakdown of workplaces by industry sector.

Three ergonomists were trained in the delivery of a participatory ergonomics for manual tasks (PErforM) intervention designed by the investigators. The intervention aimed to improve each workplace's management systems to support participation in a risk assessment and control process, and to provide supervisors and work teams with sufficient knowledge and skills to enable them to perform manual task risk assessment and control. The intervention was delivered to each workplace over a series of four sessions. In most cases these sessions were held on separate days; however some flexibility existed to accommodate individual workplace circumstances. An outline of the PErforM program is provided in Appendix A.

The intervention was delivered by the three consultants to each of the 31 workplaces over a 6 month period, although the involvement of each workplace typically spanned a period of less than 3 months. Workplaces were typically visited over several weeks to provide ongoing encouragement and support.

The investigators retrained five of the original inspectors and trained a further six inspectors in the use of ManTRA, and the second audits occurred between April to July 2002 (at least 9 months after the delivery of the intervention was complete). The government again publicized the conduct of a manual tasks 'blitz' in the mass media. The inspectors were not informed of which workplaces had volunteered for the intervention, or which had received the intervention.

2.4. *Audit tool*

The audit tool used by the inspectors (ManTRA) was designed by the investigators to serve a dual purpose: (a) to assist inspectors to form an opinion regarding the compliance of the workplace with the requirements of the relevant advisory standard (DWHS 2000), and consequently whether any formal action was required; and (b) to provide the investigators with a method of assessing the level of manual task related safety activity, relevant organizational environment variables, and an assessment of the level and nature of manual task related injury risk present in the workplace. The usability, reliability and validity of the tool was tested with government inspectors and found to be good. A copy of the complete tool, and accompanying explanatory notes, is available from the UQ Ergonomics website (ergonomics.uq.edu.au/download/mantra.pdf—password available from robin@hms.uq.edu.au).

The initial sections of the audit tool involved identifying the jobs performed by staff at the workplace and the number of staff in each category. The inspectors then selected staff to interview with the intention of selecting a 10% representative sample of non-administrative or managerial staff. The number of staff actually selected for interview varied from 1 to 13 depending on the size of the workplace and the

Table 1. Summary of workplace numbers by Group and Industry sector.

	Food	Construction	Health	Total
Experimental group	8	7	16	31
Control group	3	5	9	17
Refused	21	31	17	69
Total	32	43	42	117

inspector's perception of the degree of risk present at the workplace. At least one supervisor, and at least one person with responsibility for purchasing, were also interviewed using questions provided in the audit tool. Information on safety activity and management systems was collected from each workplace.

The audit process also involved the inspectors asking employees questions about body discomfort, the tasks undertaken, and their opinions regarding the links between particular tasks and discomfort. On the basis of this information, the inspectors' observations and knowledge of the relevant industry, the inspector selected tasks for observation and coding for risk exposure using a matrix developed for this purpose by the investigators. The inspectors were requested to select a sample of 2–3 tasks for every worker and a sample of one worker for every 10 workers at a workplace; however the number of tasks chosen for examination was influenced by the inspectors' perceptions of the risk associated with tasks performed in each workplace.

The manual tasks risk matrix (see Appendix B) involves a rating of severity (on a five point scale) of risk factors for each of five body regions. For each task, inspectors rated five body regions (lower limb, back, neck, shoulder/arms, wrist/hand) independently for seven types of risk. The types of risk were the total task time, duration of continuous performance without a break, cycle time, force, speed, awkwardness and vibration. Cycle time and duration of continuous performance scores were combined into a 'repetition' risk factor (on a five point scale) using the table presented in Appendix B. Force and speed scores were similarly combined in an 'exertion' risk factor. In this way the risk matrix was aligned with the direct risk factors for manual tasks identified in the advisory standard relevant to the jurisdiction (DWHS 2000).

For each task which was assessed, inspectors also made a decision about whether the task complied with legislative requirements or whether formal action was justified. If an inspector believed there was non compliance the inspector could: (a) issue a notice prohibiting the task from being performed until changes were made; (b) issue a notice requiring a workplace to improve the task in some way within a specified time-frame; or (c) issue formal advice regarding a manual task risk. Issued notices placed a legal obligation on the obligation holder (e.g. employee, employer, supplier), with the threat of prosecution and significant fines for lack of compliance.

Whilst the inspectors' decisions regarding whether to take action were based on the inspectors' opinions, guidance was provided to the inspectors that action may be indicated on the basis of the completed risk matrix when one or more of the following criteria were met: (a) an exertion score of five for any body region; (b) the sum of exertion and awkwardness was eight or greater for any body region; or (c) the cumulative risk score (sum of total time, exertion, awkwardness, vibration and repetition) for any body region was 15 or greater.

2.5. *Analysis*

Two groups of dependent variables are reported in this paper: manual task risk estimates and legislative compliance. Manual task risk estimates included:

- total assessed risk exposure (TARE)—the sum of cumulative risk scores for all tasks assessed at a workplace
- number of tasks assessed at each workplace
- workplace mean cumulative risk (total task risk across all body regions)

- workplace mean level of exposure to each risk factor (summed across body regions)
- workplace mean level of risk for each body region (summed across risk factors)
- workplace mean number of tasks which exceeded one or more action criteria

Legislative compliance measures included the number of enforcement actions taken by an inspector at each workplace.

The independent variables for statistical analysis were group (Experimental, Control), Industry (Food, Construction, Health) and Time (Audit 1 pre-intervention, Audit 2 post-intervention). Three-way mixed model ANOVAs (Time as a repeated measure) were computed for the variables defined above using SPSS v10. Partial eta^2 were calculated as measures of effect size (by convention, a partial eta^2 of 0.02 indicates a small, 0.15 a medium, and 0.35 a large effect).

3. Results

3.1. *Total assessed risk exposure*

Figure 1 illustrates the workplace Total Assessed Risk Exposure for the Experimental and Control groups before and after the intervention for each industry sector and for the combined industries. Whilst the Experimental group appeared to start with a higher risk exposure, following intervention there was a clear trend for the Experimental group workplace risk exposure to reduce while the Control group risk exposure tended to increase or remain stable. A Time × Group × Industry mixed model ANOVA confirmed the Time × Group interaction ($F_{1,31} = 5.40$, $p = 0.027$, partial eta$^2 = 0.148$). There were no significant main effects of Time ($F_{1,31} = 2.12$, $p = 0.155$, partial eta$^2 = 0.064$), Group ($F_{1,31} = 1.07$, $p = 0.309$, partial eta$^2 = 0.033$) or Industry ($F_{2,31} = 0.38$, $p = 0.690$, partial eta$^2 = 0.024$) nor were the remaining 2 and 3 way interactions significant (Group × Industry $F_{2,31} = 0.49$, $p = 0.618$, partial eta$^2 = 0.031$, Time × Industry $F_{2,31} = 1.08$, $p = 0.352$, partial eta$^2 = 0.065$, Time × Group × Industry $F_{2,31} = 0.20$, $p = 0.822$, partial eta$^2 = 0.013$).

3.2. *Number of tasks assessed*

Figure 2A presents the average number of tasks assessed at each workplace. A trend is evident with the Experimental group showing a decrease and with the Control groups showing a slight increase. A Time × Industry × Group mixed model ANOVA approached significance for the Time by Group interaction ($F_{1,31} = 3.74$, $p = 0.062$, partial eta$^2 = 0.108$). No main or other interaction effects were significant (eta^2 0.002 to 0.053).

3.3. *Total cumulative risk score*

Figure 2B illustrates the change in total cumulative risk estimates (workplace average sum of cumulative risk scores across all body regions) and suggests a decrease in Food Experimental group compared to Food Control group, and an increase for both Construction groups. Both Health groups started low and showed a small decrease over time. A Time × Industry × Group mixed model ANOVA for total cumulative risk found a significant main effect of Industry ($F_{2,31} = 8.98$, $p = 0.001$, partial eta$^2 = 0.220$) and a Time × Industry interaction ($F_{2,31} = 4.37$, $p = 0.021$, partial eta$^2 = 0.357$). Health was significantly lower than both Food and Construction. There was no significant Time × Group interaction ($F_{1,31} = 0.13$,

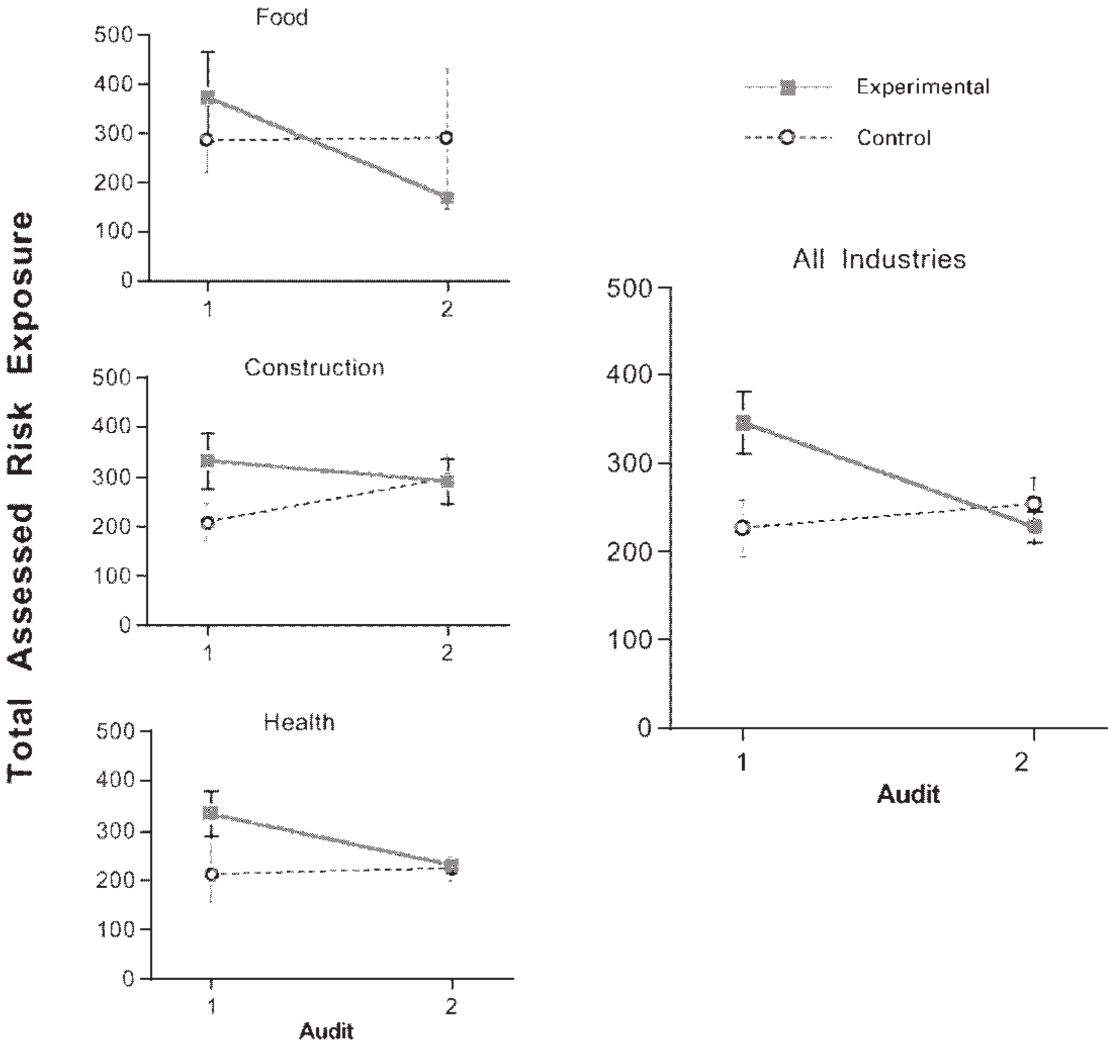

Figure 1. Workplace mean ($\pm$ SEM) Total Assessed Risk Exposure by Group, Time and Industry. Note: Some SEMs were so small as to be unnoticeable on the figure.

$p = 0.722$, partial eta$^2 = 0.004$). There were no significant main effects of Time ($F_{1,31} = 0.10$, $p = 0.751$, partial eta$^2 = 0.003$) or Group ($F_{1,31} = 0.39$, $p = 0.538$, partial eta$^2 = 0.012$) nor were the remaining 2 and 3 way interactions significant (Group $\times$ Industry $F_{2,31} = 0.51$, $p = 0.608$, partial eta$^2 = 0.032$, Time $\times$ Group $\times$ Industry $F_{2,31} = 0.30$, $p = 0.745$, partial eta$^2 = 0.019$).

3.4. *Type of task risk*

Separate Time $\times$ Group $\times$ Industry mixed model ANOVAs found no significant Time by Group interactions for any risk factor summed across body parts. There was a significant main effect of Time for task time, task duration, task force and task exertion and a significant Industry main effect for task time, task duration, task cycle time, task repetition, task awkwardness and task vibration. Examination of the changes in estimates of different types of task risk found a complex variety of responses, some of which are illustrated in figure 3.

For example, task duration risk appeared to decrease in the Experimental Food group and increase in the Experimental Construction group (figure 3A). Cycle

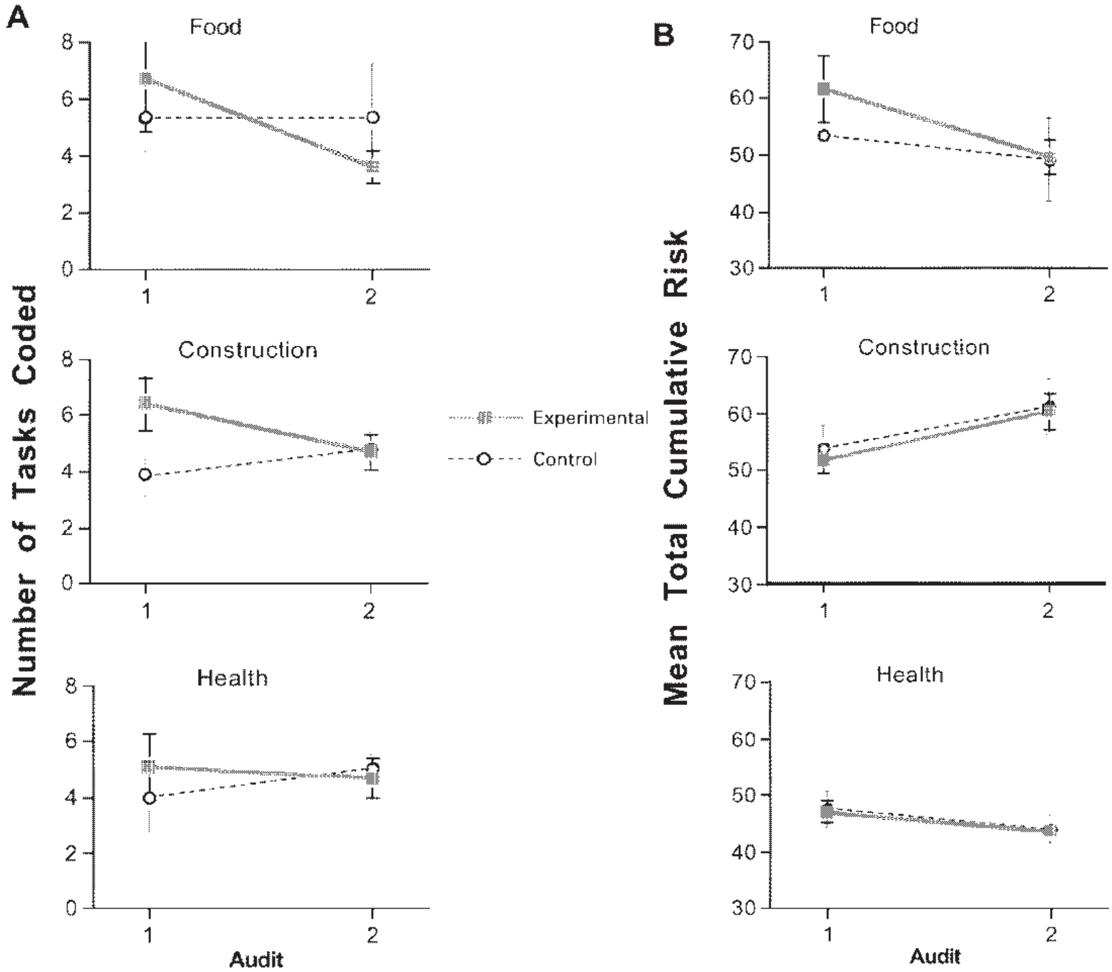

Figure 2. (A) Workplace mean (± SEM) number of tasks assessed by Group, Time and Industry; (B) Workplace mean (± SEM) total cumulative risk by Group, Time and Industry. Note: Some SEMs were so small as to be unnoticeable on the figure.

time risk appeared to have a small decrease for the Experimental Food group compared with a small increase for the Control Food group, a larger decrease for Experimental Construction than for Control Construction and a larger increase for Experimental Health than for Control Health. Task force risk appeared to have a larger decrease in Control Food and Health groups than in the comparable Experimental groups (figure 3B). Overall the trend was for more change in the time based risks and awkwardness risk for the Experimental groups than for the Control groups, with more change in the exertion risks for the Control group.

3.5. *Body part task risk*

In contrast to the variation in responses for types of task risks, the changes in risks for various body parts were more consistent. The Experimental Food group risks appeared to decrease across all body parts whereas the Control Food group risks remained the same or increased in neck and lower limb parts. The Experimental and Control Construction groups appeared to have an increase in risk in all body parts. The Experimental Health group appeared to have a decrease in risk in neck, back

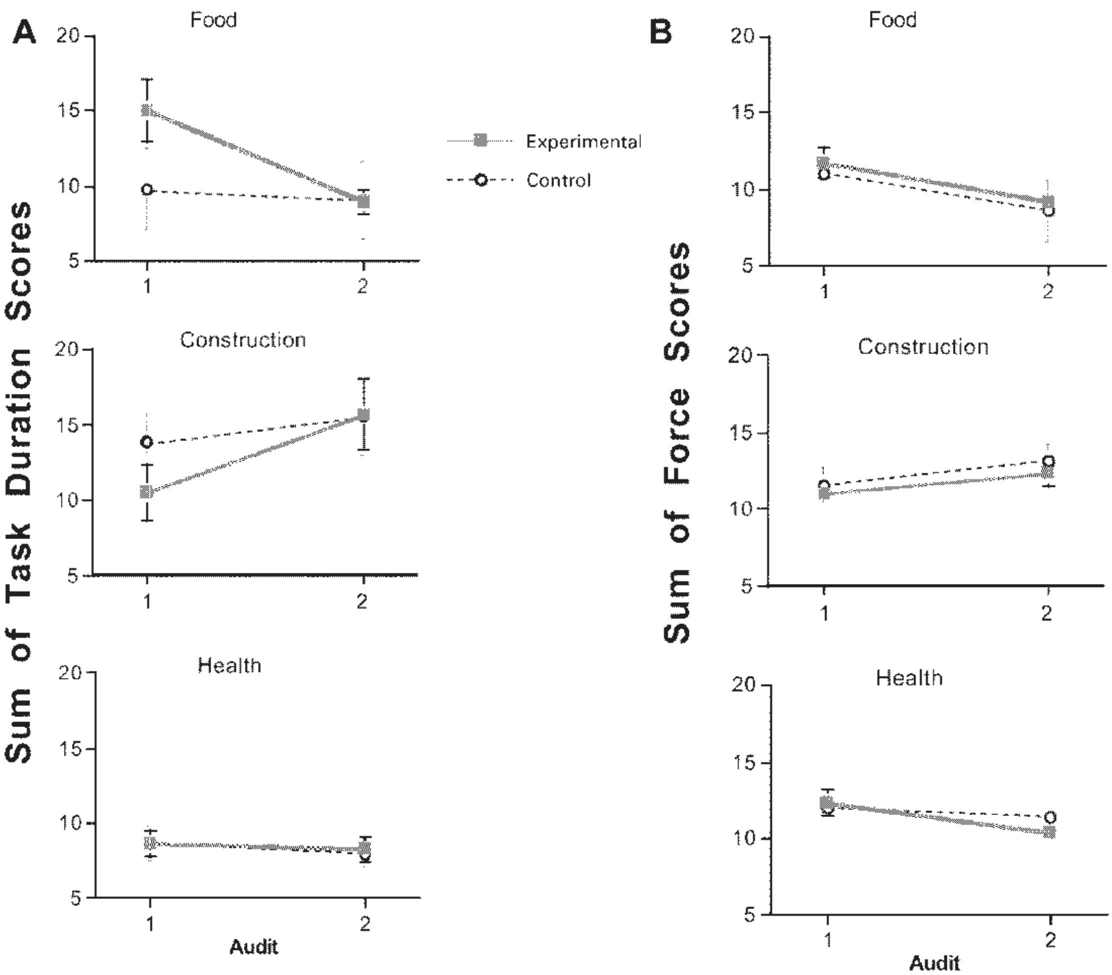

Figure 3. (A) Workplace mean ($\pm$SEM) task duration scores (summed across body parts); (B) Workplace mean ($\pm$SEM) force scores (summed across body parts) by Group, Time and Industry. Note: Some SEMs were so small as to be unnoticeable on the figure.

and lower limbs whilst the Control Health group appeared to have a decrease in all body parts (see for example figure 4)

Separate Time × Group × Industry mixed model ANOVAs found a significant main effect for Industry in the wrist and hand, back and lower limb, a significant main effect for Group in the shoulder and arm, and neck, and a Time × Industry interaction for wrist and hand, shoulder and arm, neck, and back.

3.6. *Task risk thresholds*

The audit tool suggested to inspectors that action should be considered when, for any body part, the exertion score was 5, the sum of exertion and awkwardness was 8 or more, or the total cumulative score was 15 or more. Figure 5 illustrates the number of tasks assessed at each workplace which exceeded one or more of these criteria. A decrease in the number of tasks exceeding the action criteria was evident for Experimental workplaces in each industry, but not Control workplaces in Construction and Health industries. A Time × Group × Industry mixed model ANOVA found no significant effects although Time ($F_{1,31} = 3.88$, $p = 0.056$, partial eta$^2 = 0.093$), Industry ($F_{2,31} = 1.72$, $p = 0.193$, partial

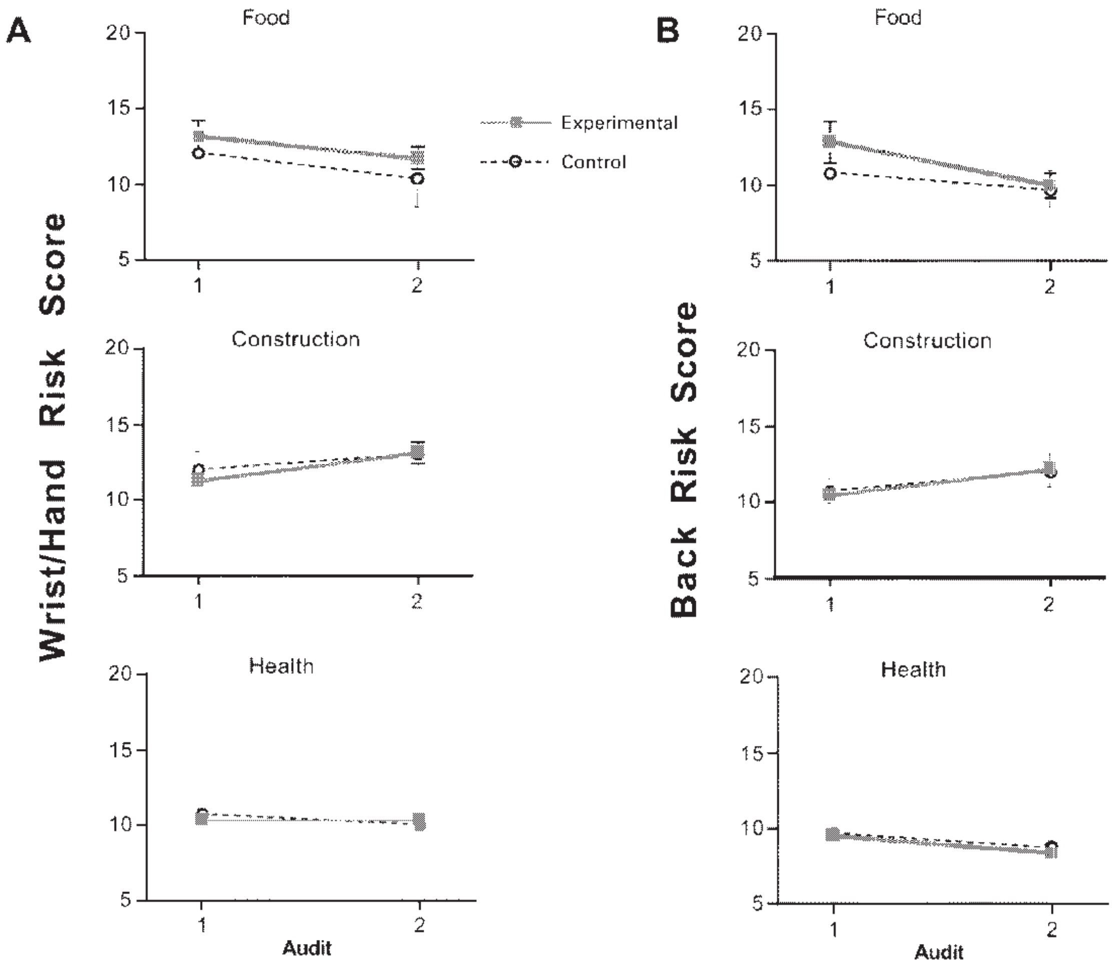

Figure 4. (A) Workplace mean ($\pm$SEM) wrist/hand risk (summed across types of risk factor); (B) Workplace mean ($\pm$SEM) back risk (summed across types of risk factor) by Group, Industry and Time. Note: Some SEMs were so small as to be unnoticeable on the figure.

eta^2 = 0.083), Time $\times$ Industry ($F_{2,31}$ = 2.20, p = 0.125, partial eta^2 = 0.104) and Time $\times$ Group ($F_{1,31}$ = 1.50, p = 0.228, partial eta^2 = 0.038) showed small to medium effect sizes.

3.7. *Inspector actions*

The number of tasks for which action was actually taken is illustrated in figure 6. The number of actions taken tended to increase for all groups in Audit 2, but less so for the Experimental groups. None of the effects reached significance with only Time ($F_{1,31}$ = 2.31, p = 0.139, partial eta^2 = 0.069), Industry ($F_{2,31}$ = 1.11, p = 0.342, partial eta^2 = 0.067) and Time $\times$ Group ($F_{1,31}$ = 0.73, p = 0.398, partial eta^2 = 0.023) showing small to medium effect sizes.

The relationship between the maximum cumulative score for any body region recorded for a task and whether inspectors took action or not is presented in figure 7. The correlation (Cramer's V) between action and maximum cumulative risk score increased from 0.40 for tasks audited during Audit 1 to 0.51 for tasks audited in Audit 2 ($p < 0.001$ for both).

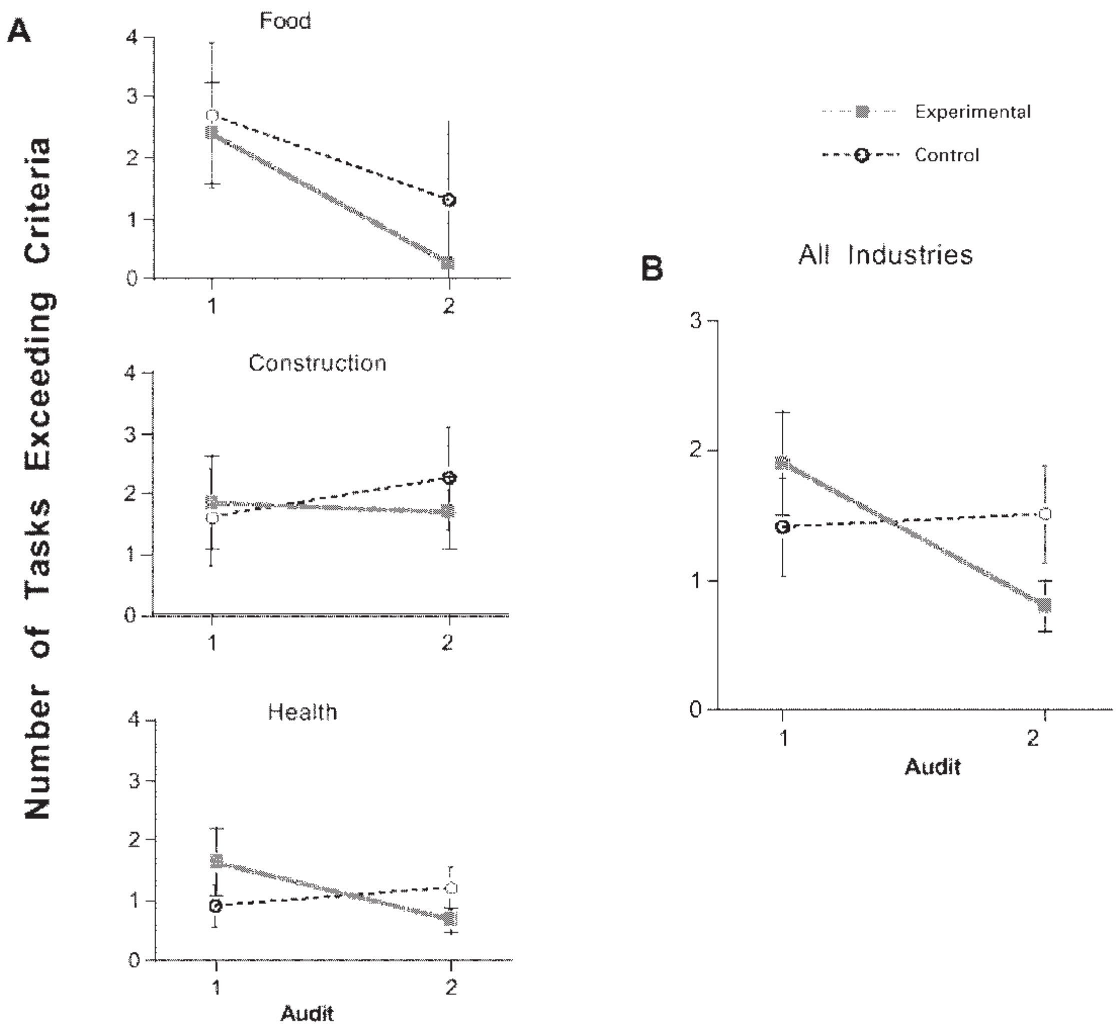

Figure 5. Workplace mean (±SEM) number of tasks exceeding one or more action criteria by (A) Group, Industry and Time and (B) by Group and Time.

4. Discussion

4.1. *Overall impact of PErforM*

The results reported above provide evidence for the effectiveness of the PErforM intervention to result in a reduction in the estimates of manual task risks at a workplace. The results also suggest PErforM resulted in an increase in legislative compliance of a workplace.

This study is the first randomized and controlled trial to evaluate a preventative participative ergonomics intervention for workplaces, and makes a major contribution to the field. The experimental design controlled for important threats to the validity of causal claims. The study consequently provides high level evidence that it was the intervention which led to the change in risk, and not some contemporaneous event such as a change in economic activity or government policy. Further, the number of workplaces involved, and their random allocation to the Experimental or Control group, ensured that the results were not dependent on individual workplace characteristics.

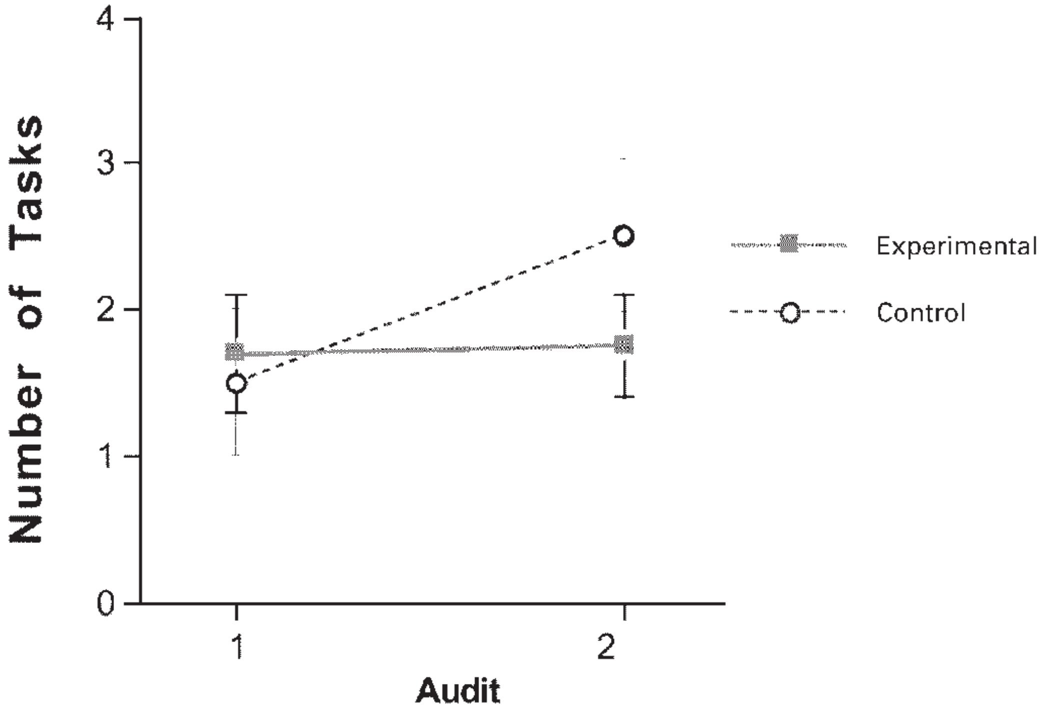

Figure 6. Workplace mean (±SEM) number of tasks for which actions were taken by inspectors.

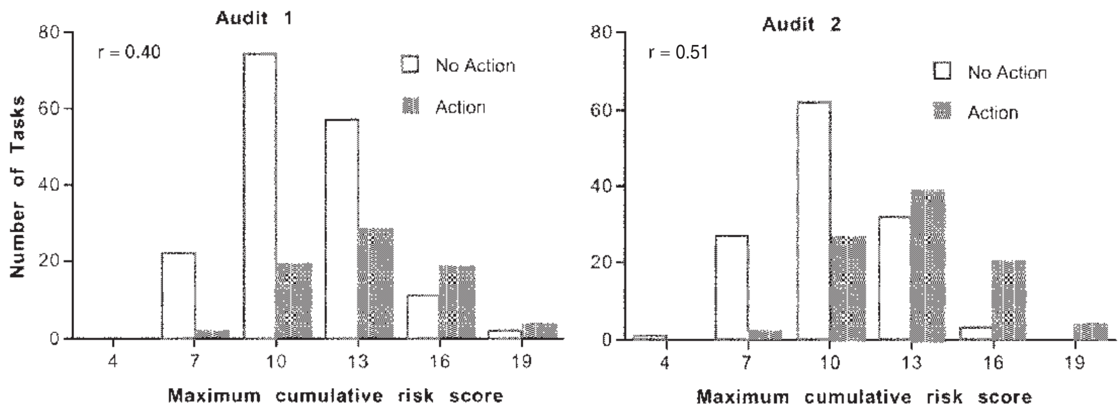

Figure 7. Maximum cumulative risk score for any body region as a function of inspector action and audit.

4.2. *Impact on manual task risk estimates*

The Total Assessed Risk Exposure clearly decreased for the Experimental group compared to the Control group (figure 1) and this change was consistent for all Industry groups. The reduction in overall workplace risk for the Experimental group was a product of both a reduction in the number of tasks which inspectors considered needed assessment (figure 2) and a reduction in the number of tasks which, when assessed, exceeded recommended thresholds (figure 5).

Whilst the estimates of risk used in this study can be criticized for involving subjective judgements, no better assessment was available. Further, using government inspectors provided practical estimates of risk which have real legal and workplace ramifications.

Examination of the overall exposure to different risk factors suggests the intervention was more effective at reducing some types of risk (figure 3). In particular, it seems that the intervention had the least influence on exertion risk factors, and greater effect on time based (task duration, cycle time) and awkwardness risk factors. This may be a consequence of a general awareness in the community of force as a risk factor, but less awareness of other risk factors. The intervention may therefore have had more effect on less well known risk factors. The effect of the intervention was fairly consistent across body regions, although to some extent this was a consequence of some time based risks being identical for all body regions (figure 4).

The reduction in risk estimates in Experimental workplaces compared with Control workplaces was mirrored in inspector actions, with the Control group receiving more formal notices and advice than the Experimental group (figure 6). This result highlights the practical outcome of the intervention in assisting workplaces to meet their legislative requirements to provide safe systems of work.

Taken as a whole, these results lead to a firm conclusion that the PErforM intervention was successful in reducing overall manual task injury risk. These data provide the best evidence to date to justify workplace based participative ergonomics interventions to reduce manual task injury risk.

4.3. *Industry differences*

The risk scores for wrist/hand and shoulder/arm and repetition risk were higher for the Food workplaces than for other industries, as would be expected given common food processing tasks. The lower back risk scores for the Health workplaces is likely to reflect the strong push in recent years in Queensland towards 'no lift' policies in health care organizations, and the incorporation of such requirements into aged care accreditation procedures.

The increase in total cumulative risk in both Construction groups is puzzling. Due to the introduction of increased taxation on building in July 2000, the construction industry was in 'boom' at Audit 1, whereas it was near 'bust' during Audit 2. The authors initially wondered whether the rise in average task risk ratings represented a reduction in safety standards to ensure economic survival. However this increase was not industry wide as it was possible to compare these to other audit data from workplaces outside South-East Queensland, and to the non-volunteer workplaces. One possible explanation came from inspectors during post Audit 2 evaluations. They reported becoming aware of workplaces which had actively hidden high risk tasks from inspectors. In one extreme case a workplace had shut down a whole production section so that high risk tasks could not be evaluated by inspectors. It was thought that the Experimental workplaces may have felt less need to hide high risk tasks in Audit 2 as they had seen the value of identifying, and then reducing, risk. The Control group may also have been less inclined to hide high risk tasks because they knew they were getting the intervention soon. The Experimental and Control groups may therefore have appeared worse than other comparison workplaces as they were prepared to be open about their risk, rather than to attempt to hide the risk.

Significant differences in work practices, workforce characteristics and culture exist between industries. These are being evaluated in the related investigation of how the intervention was implemented and what characteristics of a workplace encouraged successful outcomes.

4.4. *Use of ManTRA*

The inspectors' use of ManTRA changed slightly from Audit 1 to Audit 2. The relationship at a task level between inspectors, actions and the maximum cumulative risk score for any body region as a function of audit time (figure 7) indicates that the inspectors were more likely to take action (issue formal advice, or improvement or prohibition notices) in the second round of audits for tasks of similar risk. Focus group and questionnaire data gathered from inspectors following Audit 2 suggests that this change is likely to reflect greater confidence and experience in auditing for manual task risks. A key purpose of the ManTRA tool had been to assist inspectors to make judgements about actions. Inspectors had previously been reluctant to take action against high risk manual tasks as illustrated by very few prohibition or improvement notices being issued for manual tasks risks in the previous 7 years.

However the assessment of risk of injury due to manual tasks was not mechanical, and the judgement of the government inspectors played a key role. The selection of tasks for assessment was driven by the information obtained by the inspectors during their interviews of employees, their observations of the workplace, and their knowledge of the industry. Inspectors were asked to assess the same number of tasks in each workplace of comparable employee numbers. However inspectors tended to only proceed with a task assessment when their initial impression was that the task was high risk. This resulted in the comparison of total cumulative risk (figure 2B) suggesting little difference between groups. However the change in the number of tasks assessed and the number of tasks exceeding thresholds captured the reduction in risk following the intervention.

Given their experience with an audit based on task sampling, the authors believe it is not the optimal approach to evaluate actual risk and organizational initiatives to reduce risk. They have recommended to the government authority involved that future audits focus on the management system for risk assessment and control. Queensland legislation already requires documentary evidence of risk management activity and this evidence can form the basis of a more systematic audit. Such an audit would have the advantage of not being as open to manipulation by workplace management. For example workplaces would not be able to arrange for inspectors to come during quiet production time, nor could they hide high risk tasks by closing parts of the workplace.

4.5. *Study limitations*

Whilst this study represents the first randomized and controlled trial of participative ergonomics at a workplace level, some limitations need to be considered in evaluating the results.

The average number of tasks assessed in Audit 1 for each Experimental workplace (6.8) was greater than for the Control group (4.6). The randomization process was stratified for the three industry groups but not for the number of tasks assessed. At Audit 2 the average number of tasks for each Experimental workplace had fallen to 4.5, whereas it had risen slightly for the Control group (4.9). Audit 1 data were not available to the investigators at the time of allocation and it had been anticipated that the random nature of the allocation would have provided more similar groups. It could be argued that the reduced number of tasks assessed in the Experimental group was a regression towards the mean. However the remaining data suggest there was a real reduction in the inspector assessment of risk in Experimental workplaces.

At Audit 1 the inspectors and workplaces were blind to the group allocation (since random allocation to intervention was performed after the audit). It was intended that the inspectors would be blind to the group allocation at Audit 2 also. However the Experimental and Control workplaces could not be kept blind to their participation and on occasions they discussed workplace interventions with inspectors during Audit 2. This was discovered during focus group evaluations with inspectors following Audit 2. However it was also discovered that some Control workplaces had attempted interventions of their own (sometimes with external ergonomics assistance) and the inspectors thought some of the Control workplaces were Experimental workplaces. Any bias is consequently likely to have tended to obscure rather than amplify group differences, suggesting that the real effect of the intervention may be larger than reported. Similarly, the analysis was on a conservative 'intention to treat' basis, further minimizing the risk of falsely identifying an intervention effect. Analysis of the quality of the implementation at some workplaces is being conducted.

The authors are confident that there was no systematic bias in the allocation or assessment of the groups, and that there was a real reduction in manual task risk and a change in the related management systems at Experimental workplaces compared with Control workplaces.

4.6. *PErforM intervention*

Several aspects of the PErforM intervention were different to traditional prevention interventions.

PErforM was designed to have minimal interference with normal workplace activities. The total time required of workers (about 4 h including 'homework' activities) was much less than for other reported interventions. For example, Morken *et al.*'s (2002) intervention required 20 h. The PErforM intervention was aimed at making easy changes to workplaces to control obvious manual task risks. Based on prior experience (Straker 1990), the authors believed that significant risk reductions could be achieved with a small organizational investment, and the results of this study support this. It is hoped that, having seen the success of the small investment, workplaces will make further investments.

PErforM only addressed *prevention* of musculoskeletal disorders. Over the previous decade Australian authorities and organizations have substantially improved their occupational rehabilitation process (Innes and Straker 2002). The focus on early, managed return to work has resulted in reductions in the cost and other impacts of injuries on workers and their organizations. In the present study, interest was therefore on prevention alone, rather than prevention in combination with rehabilitation as investigated by Morken *et al.* (2002) and Loisel *et al.* (1997).

Major components of traditional prevention activities have been teaching spinal anatomy and lifting technique training. It is believed, however, that knowledge of anatomy is not essential for effective manual task risk management and that time is better spent on risk assessment and control skills. The evidence supporting the correctness of a particular lifting technique is also equivocal (Burgess-Limerick 2003, Straker 2003) and teaching lifting technique is clearly not effective in reducing musculoskeletal risk (e.g. Daltroy *et al.* 1997). Consequently, the PErforM intervention contains no lifting technique training but rather focuses on developing effective risk assessment and control skills in workers and on effective management systems within the workplace.

Whilst there was some evidence from prior experience that participative ergonomics for work teams could result in significant change (Straker 1990), the impact of these interventions had rarely been sustained. It is likely that the best way to encourage sustainability is to imbed the process of manual task risk assessment and control within each organization's management systems. A major component of PErforM was therefore the assistance provided to managers to develop appropriate policies, procedures and allocated responsibilities. Further long-term follow up is required to evaluate whether this assists sustainability.

4.7. *Intervention process*

The success of the intervention in the current study was not uniform. A concurrent qualitative review of the process of implementing the intervention was undertaken to understand why the intervention was more effective in some workplaces than others. This part of the project involved in depth interviews with workers, supervisors and managers at selected workplaces and with the ergonomics consultants. Analysis of this rich data is currently underway and aims to characterize those workplaces where participative ergonomics was most successful. It is believed that this will lead to the development of guidelines for interventions which include a set of necessary precursors for an organization to achieve prior to implementing PErforM or other similar participative ergonomics programmes.

4.8. *Application of randomised and controlled trial designs in ergonomics*

In the 1990s ergonomics struggled to demonstrate that it was worth the community and organisational investment of resources. The prolonged struggle to develop and implement a national US standard (OHSA 1999) to reduce the risk of musculoskeletal disorders associated with manual tasks was a significant example of the difficulties associated with the lack of evidence from adequately controlled studies. Randomized and controlled trials are the study designs which provide the highest level of evidence. The resource and logistic requirements of conducting a randomized and controlled trial with an ergonomics intervention are enormous compared to their traditional use in evaluating medication interventions. However this high level of evidence is required to better persuade governments and workplaces. It is hoped that the success of the current trial will encourage other ergonomics research groups and organizations to attempt further randomized and controlled trials.

5. Conclusion

This paper has reported on a study of major significance to the practice of ergonomics internationally. The study was the first randomized and controlled trial of participative ergonomics aimed at preventing musculoskeletal disorders associated with manual tasks applied to whole workplaces. As such, it represents the highest level of evidence evaluating the efficacy of preventative ergonomics.

The results of this randomized and controlled trial have demonstrated that a participative ergonomics intervention can be effective in reducing the risk of musculoskeletal disorders at a workplace. This evidence will enable ergonomists to more convincingly argue the wisdom of implementing ergonomics standards to government agencies. The evidence will also enable ergonomists to more convincingly present a case to managers that it is in an organization's best interests to invest resources in participative ergonomics.

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Appendix A

PErforM Programme Outline

The Programme involves four visits to the workplace by a PErforM consultant. Following acceptance into the programme, the manager will be contacted by a consultant to arrange the first visit. Subsequent visits will be scheduled during the management briefing during the first visit. The exact content of each contact may be modified to suit the requirements of the individual workplaces, but the following will constitute a typical arrangement.

Visit 1: *Management briefing and workplace familiarization*. The consultant will provide the manager with a thorough briefing regarding the training to be provided to staff; negotiate with the manager how the training may be delivered with minimum disruption to the workplace; and discuss the most appropriate way of assessing workplace performance (1 h). The consultant will be escorted through the workplace to gain an appreciation of the details of the workplace (1 h). The consultant will also provide the manager with information explaining the programme which is suitable for distribution to staff.

Visit 2: *Management systems, supervisor and WHSO briefing, videotaping tasks*. The consultant will assist the manager, or delegate, in the development/improvement of OH&S management systems (2 h). This will incorporate discussion of the results of the DWHS manual tasks audit. The consultant will then provide a briefing to supervisors of the work teams which will be involved in the training, and to Workplace Health and Safety Officers. This briefing will provide the supervisors with information regarding the management systems and content of the training (1 h). The consultant will request assistance from the supervisors in identifying relevant manual tasks suitable for videotaping (1 h). The objective is to obtain workplace specific illustrations to utilize in subsequent training.

Visit 3: *Risk management training*. The core of the PErforM programme is training of 1 – 3 intact work teams in manual tasks risk management. The training focuses on meeting the requirements of the manual tasks advisory standard and incorporates video of specific workplace tasks (1 – 3 work teams × 90 min). Questionnaires assessing group cohesion, work group characteristics and safety climate will also be distributed to each worker at this session.

Between visits 3 and 4 each work team will be asked to conduct and document a manual tasks risk assessment of selected tasks within their workplace and to suggest control measures.

Visit 4: *Work team debriefing*. The final visit involves a review of the risk assessments conducted by each work team to provide feedback regarding the assessments and control measures suggested (1 – 3 teams × 90 min).

Reports: The consultants will document each visit as part of the process evaluation.

Workplace follow up: The PErforM consultants will be available for further assistance for a limited time following the programme delivery. Other sources of further assistance will also be provided.

Evaluation interviews: The evaluation process also requires interviews with management, supervisors and staff on (at most) three occasions at 3 monthly intervals in the 9 months following the implementation of the programme. The purpose of these interviews is to evaluate the programme and determine how the process might be improved, not to evaluate the workplace.

Appendix B

Manual Task Risk Matrix

			Task Codes							CumulativeRisk
Body Region	Total time	Duration	Cycle time	Repetition Risk	Force	Speed	Exertion Risk	Awkwardness	Vibration	
Lower Limbs										
Back										
Neck										
Shoulder/ Arm										
Wrist / Hand										

Cumulative risk is the sum of unshaded cells.

Codes

Total time

1	2	3	4	5
0-2 hours/day	2-4 hours/day	4-6 hours/day	6-8 hours/day	> 8 hours/day

Duration of continuous performance

1	2	3	4	5
< 10 minutes	10 min - 30 min	30 min - 1 hr	1 hr - 2 hr	> 2 hr

Cycle time

1	2	3	4	5
> 5 minutes	1 – 5 minute	30 s - 1 min	10 s - 30 s	< 10 s

Force

1	2	3	4	5
Minimal force		Moderate force		Maximal force

Speed

1	2	3	4	5
Slow movements	Moderately paced	Little or no movement – static posture	Fast and smooth movements	Fast, jerky movements

Awkwardness

1	2	3	4	5
All postures close to neutral	Moderate deviations from neutral in one direction only	Moderate deviations in more than one direction	Near end range of motion posture in one direction	Near end range of motion in more than one direction

Vibration **(Whole body or Peripheral)**

1	2	3	4	5
None	Minimal	Moderate	Large amplitude	Severe amplitude

Scoring Keys for Repetition & Exertion

Scoring key for Repetition

			Duration		
Cycle Time	*1*	*2*	*3*	*4*	*5*
1	1	1	2	3	4
2	1	2	3	4	4
3	2	3	3	4	4
4	3	3	4	4	5
5	3	4	4	5	5

Scoring key for Exertion

			Force		
Speed	*1*	*2*	*3*	*4*	*5*
1	1	1	2	3	4
2	1	2	3	4	4
3	2	3	4	4	5
4	2	3	4	5	5
5	3	4	5	5	5

Action may be indicated if, for any region, the Exertion risk factor is 5, the sum of exertion and awkwardness is 8 or greater, or the cumulative risk is 15 or greater