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Estimating the effectiveness of ergonomics interventions through case studies: Implications for predictive cost-benefit analysis☆

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Abstract

Problem: Cost-benefit analysis (CBA) can help to justify an investment in ergonomics interventions. A predictive CBA model would allow practitioners to present a cost justification to management during the planning stages, but such a model requires reliable estimates of the benefits of ergonomics interventions. *Method:* Through literature reviews and Internet searches, 250 case studies that reported the benefits of ergonomics programs and control measures were collected and summarized. *Results:* Commonly reported benefits included reductions in the number of work-related musculoskeletal disorders (WMSDs) or their incidence rate, as well as related lost workdays, restricted workdays, and workers' compensation costs. Additional benefits reported were related to productivity, quality, turnover and absenteeism. *Discussion:* Benefits reported were largely positive, and payback periods for ergonomics interventions were typically less than one year. *Summary:* The results of this review could be used to develop predictive CBA models for ergonomics programs and individual control measures. *Impact on Industry:* Cost-justifying ergonomics interventions prior to implementation may help to secure management support for proposed changes. Numbers used for the benefits side of a cost-benefit analysis (CBA) need to be based on "real world" data in order to be credible. The data presented in this paper may help in the development of simple cost-benefit models for ergonomics programs and control measures.
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Keywords: Ergonomics; Musculoskeletal disorders; Cost benefit analysis; Interventions; Effectiveness

Contents

1. Introduction

Proponents of ergonomics often speak of the benefits that organizations reap when implementing both comprehensive ergonomics programs and individual control measures to reduce work-related musculoskeletal disorders (WMSDs). These benefits include not only reduced number of injuries and injury costs, but also reduced turnover and absenteeism, improved

☆ Note: More details on the case studies discussed in this paper, along with a more complete reference list, can be found at the Puget Sound Human Factors and Ergonomics Society web site: www.pshfes.org.

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product quality, and increased productivity. However, reporting of these benefits in peer-reviewed journals remains limited, and there may be a bias toward reporting only positive outcomes (Silverstein & Clark, 2004; Volinn, 1999). Fortunately, there is an increasing trend toward performing cost benefit analyses (CBA) related to safety and health interventions, and many CBA models have been developed that can be used for ergonomics interventions (Oxenburgh, Marlow, & Oxenburgh, 2004; International Labour Organization [ILO], 2002; Mossink, 2002). A significant downside to some of these models is their relative complexity and the need to develop a set of inputs for each individual organization. While cost data are readily available in most organizations, the potential benefits are often not known. These models may be better suited for post-intervention analysis, when these data are more readily available. However, there is a need for a model that predicts the benefits of an intervention, or the comparative benefits of a range of intervention options. Such a model would assist practitioners in cost justifying an investment in ergonomics interventions to management during the planning stage. In order to create such a model, one would first need to determine the likely effectiveness of different types of ergonomics interventions in reducing injuries and generating other benefits.

2. Methods

Existing CBA models were evaluated for common elements and to see if any contained predictive elements. Oxenburgh's Productivity Model (1991) does offer a "rough guide" for the effectiveness of controls, shown graphically in Fig. 1. These estimates are for safety measures in general, and controls such as barriers and light curtains are not truly relevant to ergonomics. However, Oxenburgh's model provides a good starting point for developing ergonomics-specific estimates.

Several reviews of the effectiveness of ergonomics interventions have provided useful estimates (Department of Labor and Industries [DLI], 2000; Grant & Habes, 1995; Guastello, 1993). Guastello (1993), as part of a review of the effectiveness of various accident prevention programs, evaluated two comprehensive ergonomics programs and found an average 49.5% reduction in accidents. As part of a regulatory Cost-Benefit Analysis a team of economists and ergonomists from

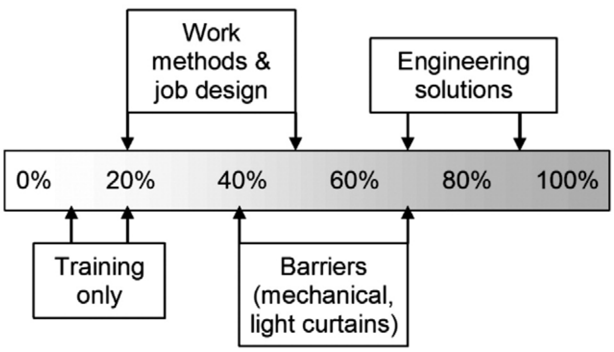

Fig. 1. Oxenburgh's (1991) estimates of the effectiveness of safety interventions.

Table 1
Washington State ergonomics rule CBA effectiveness measures

Effectiveness Measure	Number of Studies	Average Reduction	Median	Confidence Interval [a]
Number of WMSDs	37	49.5%	50%	42.2%–56.8%
Lost work days	24	65.0%	65%	54.6%–75.4%
Days per injury	3	56.6%	65%	36.6%–76.6%
WMSD costs	22	64.8%	64%	55%–74.6%
Cost per claim	5	43.6%	56%	8.4%–78.6%

[a] Computed 95% confidence interval.

the Washington State Department of Labor and Industries (DLI, 2000) estimated the benefits of ergonomic interventions by evaluating the literature on actual ergonomic programs in the workplace.

The DLI team carried out a literature search focusing on reports and publications evaluating the effectiveness of ergonomic interventions at the workplace. A total of 63 reports and publications on the success of ergonomic programs were evaluated and determined to be of sufficient quality for determining rule effectiveness. These case studies, many of which were from peer-reviewed sources, covered a wide range of work environments. Several of the published sources were, themselves, reviews of a number of case studies. The DLI review focused mainly on the reduction of WMSDs and related costs, although some information on productivity and other benefits were also recorded. Publications and reports that were anecdotal in nature, or lacked detailed information, were not included in this evaluation (DLI, 2000). Table 1 summarizes the average and median effectiveness of the workplace ergonomic interventions, as well as the confidence intervals around the averages.

The observed average reduction in number of WMSD injuries was 50%, while the average reduction in WMSD costs was 64%. The literature search also revealed a decrease in the severity of WMSD injuries that were reported after implementation of ergonomic programs, as seen in the reduction in days per injury and cost per claim. Confidence intervals for mean effectiveness rate (central estimate) of 50% were established based on the variance of the effectiveness parameter reported in the intervention studies evaluated.

Along with other evidence, the DLI economists used the results of this review to develop conservative estimates of a 40% reduction of WMSDs and a 50% reduction of WMSD costs for ergonomics interventions in compliance with the proposed rule. While the review provided adequate evidence for this conclusion, insufficient information was available to make assumptions regarding other benefits, or to estimate the effectiveness of different types of individual control measures. This raised the question: What results would one find if one 'cast a wider net,' searching not just textbooks and peer reviewed journals, but also the rapidly growing set of case studies, many of them anecdotal, that are published on the Internet?

In order to answer this question, a search of the World Wide Web was performed on popular search engines using several

Table 2
Effectiveness measures from all 250 case studies

Effectiveness Measure	Number of Studies	Average	Median	95% CI	Range
Number of WMSDs	90	59% ↓	56% ↓	54%–64%	8%–100% ↓
Incidence rate*	53	65% ↓	67% ↓	57%–73%	9%–100% ↓
Lost workdays*	78	75% ↓	80% ↓	70%–80%	3%–100% ↓
Restricted days*	30	53% ↓	58% ↓	42%–64%	5%–100% ↓
Workers' comp costs*	52	68% ↓	70% ↓	62%–74%	15%–100% ↓
Cost per claim*	7	39% ↓	50% ↓	11%–67%	−20%–81% ↓
Productivity	61	25% ↑	20% ↑	20%–30%	−0.2%–80% ↑
Labor costs	6	43% ↓	32% ↓	17%–69%	10%–85% ↓
Scrap/errors	8	67% ↓	75% ↓	59%–85%	8%–100% ↓
Turnover	34	48% ↓	48% ↓	40%–56%	3%–100% ↓
Absenteeism	11	58% ↓	60% ↓	43%–63%	14%–98% ↓
Payback period	36	0.7 years	0.4 years	0.4–1 year	0.03–4.4 years
Cost:Benefit ratio	5	1:18.7	1:6	1:−7.6–1:45	1:2.5–1:72

*Due to WMSDs.
↓ Down arrows represent a reduction in the effectiveness measure.
↑ Up arrows represent an increase in the effectiveness measure.

different combinations of the terms "ergonomics," "solutions," "interventions," "cost," "benefit," "analysis," and "effectiveness." The search revealed numerous case studies on the benefits of both ergonomics programs and individual control measures, including several collections of "success stories" that were judged to be from reliable sources (Hendrick, 1996; OSHA, 1999; U.S. Department of Defense, 2004; Ohio Bureau of Workers' Compensation [BWC], 2002). Case studies were included only if there was enough detail on the intervention to determine that it was likely to have resulted in the benefits that were attributed to it. Case studies were excluded from the analysis if they were related more to human factors design than ergonomics. Also, case studies that reported other safety and health interventions in addition to ergonomics were excluded if they did not estimate the effect of the ergonomics interventions alone. Effectiveness measures were included in the analysis only if they were reported either as a percentage change, as pre/post data from which a percentage change could be calculated, or as a standard financial outcome (e.g., benefit:cost ratio or return on investment). Finally, effectiveness measures that were obvious outliers (e.g., a reported productivity increase of 400%) were excluded.

The remaining case studies were combined with the 63 published studies from the DLI regulatory CBA, along with additional, more recently published articles. The industry, type of intervention, analysis period, costs, benefits, and resulting savings for each of the case studies were entered into a database. Duplicates were screened out by searching the database by industry type for identical numerical values among the effectiveness measures. Descriptive statistics and confidence intervals were calculated using Microsoft Excel 2003. The 95% CI was simply computed as +/−1.96 standard deviations from the mean of the observed values, even when only two values were observed. In order to assess for publication bias, a funnel plot of sample size versus percentage injury reduction was created using a subset of 30 case studies that reported these data.

3. Results

The search resulted in a collection of 250 case studies, including the 63 studies from the DLI review, representing a variety of industries and types of intervention. Eighty-seven of the case studies described interventions in manufacturing industries, 40 were in an office environment, and 36 were in a healthcare

Table 3
Effectiveness measures from 114 ergonomics program case studies (excluding office)

Effectiveness Measure	Number of Studies	Average	Median	95% CI	Range
Number of WMSDs	66	57% ↓	55% ↓	51%–63%	8%–100% ↓
Incidence rate*	24	57% ↓	50% ↓	45%–69%	9%–100% ↓
Lost workdays*	44	72% ↓	79% ↓	65%–79%	15%–100% ↓
Restricted days*	9	46% ↓	37% ↓	31%–61%	16%–77% ↓
Workers' comp costs*	42	67% ↓	68% ↓	60%–74%	15%–100% ↓
Cost per claim*	6	32% ↓	32% ↓	3%–61%	−20%–76% ↓
Productivity	6	46% ↑	40% ↑	22%–70%	10%–80% ↑
Labor costs	2	28% ↓	28% ↓	12%–44%	20%–36% ↓
Turnover	9	36% ↓	40% ↓	23%–49%	3%–68% ↓
Absenteeism	2	79% ↓	79% ↓	42%–116%	60%–98% ↓
Payback period	1	0.19 years	0.19 years	-	-
Cost:Benefit ratio	2	1:2.8	1:2.8	1:2.7–1:3.2	1:2.5–1:3

*Due to WMSDs.

Table 4
Effectiveness measures from 40 office ergonomics intervention case studies

Effectiveness Measure	Number of Studies	Average	Median	95% CI	Range
Number of WMSDs	5	61% ↓	50% ↓	41%–81%	43%–100% ↓
Incidence rate*	1	64% ↓	64% ↓	-	-
Lost workdays*	4	88% ↓	91% ↓	74%–102%	70%–100% ↓
Restricted days*	1	100% ↓	100% ↓	-	-
Workers' comp costs*	3	81% ↓	80% ↓	72%–90%	74%–89% ↓
Cost per claim*	1	81% ↓	81% ↓	-	-
Productivity	25	17% ↑	12% ↑	11%–23%	−0.2%–64% ↑
Errors	2	32% ↓	32% ↓	−15%–79%	8%–56% ↓
Turnover	2	87% ↓	87% ↓	85%–89%	86%–88% ↓
Absenteeism	3	46% ↓	50% ↓	11%–81%	14%–75% ↓
Cost:Benefit Ratio	3	1:1.78	1:1.5	1:1–1:2.6	1:1.3–1:2.6
Payback period	9	0.4 years	0.4 years	0.18–0.62 yrs.	0.06–1 year

*Due to WMSDs.

Table 5
Effectiveness measures from 36 healthcare program case studies

Effectiveness Measure	Number of Studies	Average	Median	95% CI	Range
Number of WMSDs	21	61% ↓	60% ↓	51%–71%	18%–100% ↓
Incidence rate*	10	56% ↓	46% ↓	37%–75%	16%–100% ↓
Lost workdays*	15	74% ↓	80% ↓	64%–84%	38%–100% ↓
Restricted days*	8	49% ↓	43% ↓	23%–75%	5%–100% ↓
Workers' comp costs*	13	70% ↓	73% ↓	58%–82%	35%–99% ↓
Cost per claim*	1	20% ↑	20% ↑	-	-
Turnover	8	37% ↓	33% ↓	15%–59%	3%–100% ↓
Absenteeism	1	98% ↓	98% ↓	-	-
Payback period	4	0.28 years	0.17 years	−0.18–0.74 yrs.	0.06–0.71 years

*Due to WMSDs.

setting, with the remainder in a variety of other industries. Just over 150 of the case studies reported the results of ergonomics programs, with the remainder being cost-benefit analyses of individual control measures. Individual control measures were further broken out by the type of risk factor they addressed (e.g., lifting, awkward postures) and the way in which they eliminated or reduced exposure to risk factors (e.g., substituted mechanical equipment for manual lifting, reduced level of exposure by improving location of the lift or reducing weight of the object).

Table 2 shows the benefits reported for all 250 case studies. Tables 3–5 show reported benefits from case studies in non-office environments, office environments, and healthcare, respectively. Table 6 shows the reported effectiveness measures for case studies on individual control measures such as lift assist devices, workstation redesign, and tool redesign.

The individual control measure case studies were further reviewed in order to break them out into four categories of effectiveness:

1. Controls that, as described, were likely to eliminate the hazardous exposure (e.g., substituting a mechanical lift device for a manual lift; semi-automation of a process);

Table 6
Effectiveness measures from 96 individual control measure case studies

Effectiveness Measure	Number of Studies	Average	Median	95% CI	Range
Number of WMSDs	18	64% ↓	62% ↓	51%–77%	25%–100% ↓
Incidence rate*	28	71% ↓	73% ↓	61%–81%	14%–100% ↓
Lost workdays*	30	77% ↓	84% ↓	67%–87%	3%–100% ↓
Restricted days*	20	54% ↓	61% ↓	39%–69%	5%–100% ↓
Workers' comp costs*	6	69% ↓	79% ↓	49%–89%	33%–91% ↓
Productivity	30	28% ↑	25% ↑	21%–35%	7%–67% ↑
Labor costs	4	51% ↓	54% ↓	14%–88%	10%–85% ↓
Scrap/errors	6	79% ↓	90% ↓	58%–100%	35%–100% ↓
Turnover	23	50% ↓	58% ↓	40%–60%	3%–100% ↓
Absenteeism	6	57% ↓	64% ↓	40%–74%	23%–75% ↓
Payback period	25	0.82 years	0.40 years	0.41–1.23 yrs.	0.03–4.40 years
Cost:Benefit ratio	3	1:29.3	1:10	1:−12.6–1:71.2	1:6–1:72

*Due to WMSDs.

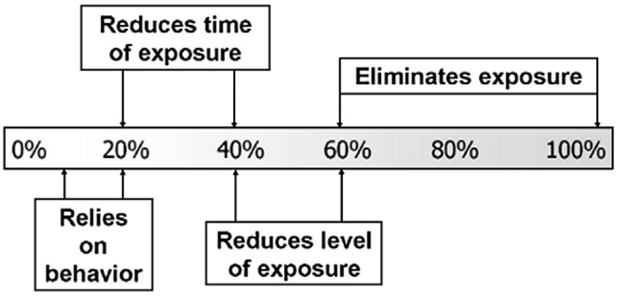

Fig. 2. A proposed relationship between level of control and estimates of effectiveness based on results from case studies.

2. Controls that would reduce the level of exposure (e.g., improving the location or reducing the weight of the lift; modifications to workstations or tools)
3. Controls that would reduce the time of exposure (e.g., rotating to tasks with different or no risk factor exposure); and
4. Controls that primarily relied on employee behavior (e.g., training only or team lifting).

Fig. 2 shows the results of this effectiveness categorization. The effectiveness estimates are based on the range of reductions in WMSD numbers and incidence rates, as well as lost workdays and workers' compensation costs, both of which are indicators of injury severity. Effectiveness estimates are presented as a range rather than as an average due to the variability of the measures and the relatively small number of studies in each category. While the estimates of the effectiveness of controls that eliminate or reduce the level of exposure are based on a reasonable number of case studies (37 and 57 studies, respectively), the estimates for reducing time of exposure and controls that rely on behavior are based on only one case study each, and therefore should be considered more professional opinion than evidence-based estimates.

4. Discussion

The theory that reporting of results is biased toward positive outcomes would appear to be borne out by the fact that, out of 525 individual effectiveness measures reported, only two were negative, a 0.2% reduction in productivity in an office setting (offset by a 7.75% reduction in errors) and a 20% increase in costs per claim for a healthcare employer (although overall workers' compensation costs for this employer were reduced by 35% for the same period). The scatter plot of sample size versus injury reduction did show a funnel shape, with more variability in effect size among the studies with smaller sample sizes. There did not appear to be any asymmetry in the shape of the plot, such as would be expected if there were a lack of reporting of studies with no or negative effects (Peters, Sutton, Jones, Abrams, & Rushton, 2006). Comparing Tables 1 and 2, the results with the Internet case studies added in were, in general, more positive than those from the DLI review alone, although the case study numbers are mostly within the 95% confidence interval used by DLI. Comparing Figs. 1 and 2, it appears that the effectiveness estimates from the case studies compare fairly well with those proposed by Oxenburgh (1991).

In addition to the injury-related effectiveness measures, productivity, turnover, absenteeism, and payback period were some of the more commonly reported metrics. The types of effectiveness measures reported seem somewhat dependent on their importance to the industry in which the intervention took place. For example, productivity was reported in most of the office ergonomics case studies; however, it was not reported at all in the healthcare sector, which instead chose lost workdays, restricted days, and turnover as the next most important metrics to consider after injuries and costs. This seems logical, since productivity is less important in patient care than is quality, which can be negatively affected by staffing shortages. The non-injury-related effectiveness measures also proved quite positive; for example, 28 out of the 36 reported payback periods were less than one year.

5. Conclusions

These results can have implications for the design of CBA models. For example, the fact that most interventions have payback periods of less than one year would allow for simpler models that do not have to account for depreciation or discounted cash flow. Since productivity was a commonly reported benefit, it can be argued that it should be included in even a basic model, while the effects on absenteeism, turnover, and error rates might be reserved for more complex models. Finally, these results provide an opportunity to develop CBA models for different work settings, such as healthcare, office, or industrial, as well as different situations, such as implementing a comprehensive program versus an individual control measure.

There are numerous limitations to the use of these data, however. The aforementioned bias toward reporting successful interventions would suggest that more conservative numbers might be appropriate in a predictive model, although one could argue that the goal of implementing an ergonomics intervention is to be successful, and therefore the more optimistic numbers are appropriate. This large a number of positive case studies would tend to reinforce the assertion that, when implemented correctly, ergonomics interventions can provide considerable benefits to organizations. Despite the large overall number of examples, some of the categorized results such as the benefits from individual control measures have relatively few examples and quite a bit of variability, and so these numbers should be used cautiously. Additionally, a relatively small proportion of the case studies came from peer reviewed sources, and even fewer are from randomized and controlled studies. Therefore, it is possible that some of the benefits seen were not solely due to the ergonomics interventions. In fact, the wide range of reported effectiveness for essentially similar control measures may be due to factors such as variations in the quality of each organization's overall safety and health program, and the level to which they have addressed other potential contributors to injury rates, such as psychosocial risk factors.

Some questions also remain about the way in which the case studies report productivity increases, and how this would translate into a benefit to the organization's bottom line. For example, an intervention may increase productivity for a single process by 25%, but does this translate to measurable savings in reduced overtime costs or increased sales for the organization? The wide range of productivity numbers that were reported does seem to indicate that organizations use different definitions when reporting productivity. There were also considerable differences in time periods over which the benefits were reported. While some organizations may have reduced WMSD costs by 80% over a one-year period, others may have reported the same benefit but over a three- or five-year period, or not reported a time period at all. This makes estimating a typical annual benefit for an intervention difficult. Issues such as these must be resolved before these results can be put to practical use in a predictive model. Certainly once a predictive model is developed, it will need to be validated through more intervention case studies similar to those upon which it is based.

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