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Effectiveness of ergonomics interventions to prevent musculoskeletal disorders: Beware of what you ask

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Abstract

As ergonomics has grown and expanded, one area of research and practice that has become more prominent is that dealing with musculoskeletal disorders. For various reasons, the increased scrutiny on the effectiveness of ergonomics for preventing musculoskeletal disorders has led to a recent boom in intervention effectiveness research. Although this has considerable intuitive appeal, several reasons why some intervention research can be detrimental to the field are outlined. The fact that many situations will lead to statistical insignificance or weak evidence has implications for creating a negative bias in the literature. The myriad barriers to intervention research often lead to murky answers to the omnibus hypothesis that an intervention is effective, whereas an alternative, of showing productivity gains instead of decreased morbidity, increases the risk that interventions become ergonomic pitfalls if the productivity gains result in increased throughput rates.

Relevance to industry

The evaluations of intervention effectiveness influence whether some ergonomic interventions are selected and implemented in industry. The potential pitfalls when researching interventions and implications for ergonomics are discussed.

Keywords: Intervention; Musculoskeletal disorders; Epidemiology

1. Introduction

Ergonomics has developed from a narrow and well-defined field of research and practice in the middle of the last century into a more compartmentalized but broader field characterized by component domains that act semi-independently. Early texts (e.g. Murrell, 1965; Singleton, 1974) had an underlying theme of enhancing human performance, particularly acute production system responses such as productivity and error rates. In the past 25 years or so, one domain that has grown considerably is that dealing with the more insidious responses of the musculoskeletal system to working life, mainly those responses that have been termed "musculoskeletal disorders" or related variants. This is not to say that ergonomics did not consider the musculoskeletal system early on, as some of the earliest work in areas that what would evolve into ergonomics goes back to the 19th century. Early research focused on the mechanics and physiology of the musculoskeletal system (e.g., Amar, 1920). The distinction is that the focus changed, or more specifically expanded, from those responses that could be measured contemporaneously with the work being performed (e.g., fatigue indicated by changes in an electromyography signal, oxygen consumption) to those responses believed to be associated with repeated task performance over weeks or months (e.g., tendonitis, carpal tunnel syndrome).

Westgaard and Winkel (1996) describe the changes in focus over time as 'schools,' with School I-performance criteria focusing on production efficiency, School II-fatigue criteria focusing on physiologic fatigue (localized muscle and whole-body), and School III-musculoskeletal health criteria focusing on what are now termed musculoskeletal disorders. Although all of these criteria continue to be used

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to design and evaluate production and service systems, currently School III is the focus of ergonomic intervention research.

The prevention of musculoskeletal disorders and associated disability is now a prominent domain of ergonomics, and interfaces with other disciplines including medicine, epidemiology, rehabilitation, and occupational therapy. However, ergonomics itself as a field is largely viewed as being responsible for prevention (practice) as well as providing the scientific foundation (research) for informing practice. As such, this particular application of ergonomics has brought external scrutiny to the field, in part because of the contentious political nature of musculoskeletal disorders in some countries, additionally because ergonomics has promoted itself as being a cost-effective means of preventing musculoskeletal disorders (Hendrick, 1996). In fact, the term "ergonomic intervention", at least in the United States, commonly has an implicit application of preventing musculoskeletal disorders.

The topic of "intervention effectiveness" is expanding in popularity as evidenced by, for example, special issues of journals (including this issue of *International Journal of Industrial Ergonomics*) and conference sessions devoted to exploring the issue. The author is of the opinion that this is primarily the result of the contentious political nature of musculoskeletal disorders in some countries and the notion of cost effectiveness of ergonomics that has been popularized. In the case of politics, there have been heated debates over the issues of work-relatedness and whether ergonomics is capable of solving musculoskeletal disorders in the workplace. Thus, evidence of intervention effectiveness is a natural weapon to use by those that support ergonomics in such debates. Evidence of cost effectiveness also appeals to business, particularly when capital expenditures need to be rationalized through determining payback periods and similar economic metrics.

In spite of the increased attention to intervention effectiveness research and the potential benefits with respect to making ergonomic improvements, there are nevertheless some downsides to this line of research. Research results can be used to support ergonomics practice and individual recommendations of practitioners, and equally, some results can be used to justify not making improvements. Likewise, when political debates surrounding musculoskeletal disorders occur, the author believes the importance of individual research findings are often amplified by those of different sides of the debate, and negative or inconclusive findings are used more broadly to assail the scientific basis of ergonomics. Several of the reasons why negative findings and especially inconclusive findings may be likely and even predicted at the onset of a study will be explored, and the potential implications for the field will be suggested. This is not intended to be a comprehensive review, rather an overview of major issues.

2. Counting angels dancing on the head of a pin?

When evaluating the effectiveness of an intervention to reduce the risk of musculoskeletal disorders, two of the most appealing measures of effectiveness are the reductions in incidents and the length of associated sickness absence. The definition of incident ranges from self-reports of discomfort to more formal counts such as workers compensation claims or definitions based on government reporting systems (e.g., Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) in the UK or Occupational Safety & Health Administration (OSHA) 300 logs in the US). Most often, these metrics are compared before and after the intervention to investigate 'effectiveness.'

Unlike early metrics of human performance used by ergonomists (such as error rates and productivity), musculoskeletal disorders are more insidious in their onset, are often without a discrete beginning point, may last for weeks or months possibly with recurrent patterns, and may or may not lead to sickness absence or even reporting. In many cases, and in particular where materials handling problems are involved, ergonomists use tools derived from earlier task-analytic approaches better suited to analyzing discrete system outcomes than musculoskeletal problems (Dempsey and Mathiassen, 2006). Thus, one of the stumbling blocks to intervention research is that there often is no discrete onset, the exposure and morbidity history accumulated before the intervention may still affect outcomes after the intervention, and the recurrence of an earlier episode after the intervention may cloud the benefits. This presents an inherent measurement problem for the outcome measure particularly when there are constraints on the length of the research project or when 'management' wants an answer sooner that good research practices permit.

When the goal of a research or internal study is to show fewer musculoskeletal incidents occurred after the intervention than before, some measure of statistical certainty is often used to provide evidence. Unfortunately, in a number of situations the issues mentioned in the previous paragraph coupled with basic probability principles lead to this question being intractable. In the case of individual jobs or even small departments, the number of workers with similar tasks is often small and the probability of musculoskeletal problems is often low if measures such as workers compensation claims are used. For example, if the risk of sickness absence due to low back pain in a year decreased from 6% to 3% among seven workers performing a job that was changed, it is unlikely that any study design would be able to capture this effectiveness with the commonly accepted statistical significance level of $\alpha = 0.05$. However, as ergonomists, this is the type of change we would welcome given that risk has been reduced by 50%! Discomfort and similar outcomes with higher prevalence rates may reduce the problem somewhat, but often the situation makes even changes in outcomes with higher prevalence difficult to 'prove.'

The problems associated with achieving some degree of statistical certainty were well illustrated by the study performed by Trevelyan and Haslam (2001) in a brick making factory. Despite successful engineering changes, the small number of workers was a barrier to statistical analysis. Although the results suggested that the intervention was beneficial and the engineering changes would be judged to reduce physical loading by just about any practicing ergonomist, there was insufficient evidence to yield more conclusive findings. The conclusion drawn from this study could certainly vary depending on what side of an argument regarding ergonomic interventions you are on, and may encourage employers with similar operations to resist change.

3. What is an appropriate research question?

The term "ergonomic intervention" often implies that deficiencies from an ergonomic standpoint were either eliminated or reduced, and in the case of musculoskeletal disorders this implies reducing exposure to risk factors such as high forces, awkward postures and repetition rates. In reality, the case where an exposure is eliminated through automation of process design would probably not be the topic of research since there is no question about effectiveness. Thus, there may be an inherent bias in the archival literature in that these studies would not be published since the outcome is deterministic, and deterministic studies do not have much appeal to editors, reviewers and readers that expect *p*-values.

On the other hand, automating a process may have effects on up- or down-stream processes, particularly in manufacturing, and effectively introduce new sources of risk. For instance, bottlenecks in assembly lines are often indicative of, or caused by, ergonomic problems. If the change effectively addresses the reason for the bottleneck, there is the potential for creating new problems downstream. Similarly, the automation may pose new ergonomic challenges whether they are highly repetitive motions to operate the process or classical vigilance and inspection problems. Although these are real problems for the ergonomist, they can be particularly challenging when evaluating the effectiveness of the intervention. If an intervention causes such problems but solves the originally intervened upon task, should the intervention be judged acceptable?

For most musculoskeletal interventions, particularly those reported in the literature, there are modifications to reduce exposure to existing tasks, equipment, and machines. Often times, the task or process is still performed after the intervention and the morbidity associated with the task is the subject of the study. These are perhaps the most difficult situations to study, as the quantification of exposure and the reduction in exposure are often difficult. The reduction in exposure can be dynamic, as this depends on factors that may include how successfully the intervention was implemented, the acceptance of the interventions by the workers (both short and long term), and the possible effects of the intervention on work pace and frequency (see next section). Thus an omnibus hypothesis of the effect of an intervention on musculoskeletal outcomes may in fact be testing something quite different, and any inference drawn misleading. This is a fairly subtle but critical issue to be addressed when the research question for an intervention study is framed. For example, the effect of a new materials handling device such as a hoist on musculoskeletal incidence may be affected by whether or not the device reduced exposure to risk factors and whether or not the workers continued to utilize the intervention after the initial observation by researchers. While both of these form the basis of valid research questions, they are quite different from the hypothesis of the effect of the intervention on musculoskeletal disorders, and the distinction has significant impact on the inference drawn from the study. The point is not to review all barriers to being able to answer the original research question, but it is fair to say to the above examples only scratch the surface of the underlying problems (e.g., see Whysall et al. (2006) for a more comprehensive overview).

Although broader in scope than just musculoskeletal disorders, the intervention study by Sinclair et al. (2003) provides an excellent example of a study that was inconclusive, in part because the research question was overly broad. The authors ultimately concluded that the lack of statistical findings of evidence of the training intervention may have been due to methodological issues of conducting a large study. A number of potential issues were suggested, but no real conclusions drawn from a significant research effort.

One of the most difficult questions to answer in some cases is whether or not exposure was reduced. Continuing with the mechanical aid example, the stresses on the low-back can be quite different when lifting and carrying boxes versus using a mechanical aid. Postures may be very different and choosing exposure parameters or analysis tools that are capable of differentiating the situations may be next to impossible. In this case, the research question may have to be whether or not the mechanical aid is an effective intervention, which is fraught with numerous problems discussed earlier. A controlled laboratory study or series of studies may be a more appropriate means of investigating the intervention. If possible, the much more straight-forward research question of whether exposure was reduced by the intervention can provide a more definitive conclusion. For example, the paper in this issue by Southard et al. (2007) describes a comparison of muscle activity and joint loading for two methods of weighing calves. The analysis provides convincing data to show the reduction in biomechanical exposure for the intervention. Although it would have been possible to attempt to obtain pre- and post-intervention morbidity data to determine the effectiveness, such an effort would have numerous barriers, especially finding a sizeable subject sample and being able to isolate the influence of a task performed infrequently from a broader set of mechanical exposures encountered during other farm tasks. By constraining the research question to one that was answerable, this intervention has a greater chance of being adopted by others faced with the same problem.

4. Robbing Peter to pay Paul?

Because of the increased reliance on cost justification of a redesign based on ergonomics analysis, the use of productivity gains as a justification has become fairly common. Perhaps even more importantly, productivity can be used to circumvent the problems associated with using morbidity reduction as a justification. Productivity improvements can usually be predicted prior to the intervention. As mentioned earlier, many of the task-based ergonomic analyses of manual materials handling have roots in the time and motion studies (e.g. Gilbreth and Gilbreth, 1917) that formed the basis of the field of production engineering (Dempsey and Mathiassen, 2006), thus it is natural to consider ergonomics and productivity during an analysis. Productivity gains are clearly an intuitive means of appealing to management for the capital expenditures required for an intervention, and can be particularly effective when the justification is made to someone without ergonomics training or is not a stakeholder in worker safety and health. Productivity analyses provide a common language amongst the different stakeholders.

One problem with pointing out productivity benefits is that the gains may suggest secondary changes to the job or task following the ergonomic changes that can result in what Winkel and Westgaard (1996) termed the 'ergonomic pitfall.' Thus, when ergonomics and production engineering function separately, there is always the risk that gains in productivity provided by the ergonomists will be robbed by the production engineers resulting in an increase in pace, ultimately resulting in a net increase in the repetitiveness of a job. In fact, why would not management, particularly those under pressure to reduce costs, take advantage of the productivity gains offered by the ergonomist? This is compounded by the fact that production bottlenecks may be caused by ergonomic deficiencies, or at least can be solved by an ergonomist. From a production engineering standpoint, the bottleneck can be alleviated by increasing throughput at that point in the production chain which may be undesirable from an ergonomics standpoint.

Using productivity as a means to justify the implementation of an ergonomics intervention is an effective method of convincing management to implement the intervention. Productivity gains can often be predicted using traditional work measurement techniques or simply by demonstrating wasteful motions or task elements that will no longer need to be performed after the intervention. However, temporal demands of work have long been known to influence task demands, whether the task requires perceptual, cognitive, physiological or biomechanical capacity. In the case of musculoskeletal disorders, frequency (or repetitiveness) can contribute to the risk of musculoskeletal disorders. Using productivity gains will often appeal to management in more ways than one, so care should be taken when using this measure.

5. Discussion and conclusions

Although demonstrating effective interventions provides evidence of the value of ergonomics, the author is of the opinion that greater consideration needs to be given to whether or not all intervention research is beneficial to the field of ergonomics. In summary, the reticence is for three primary reasons: (1) in many situations, answering the question of effectiveness will be intractable from a statistical standpoint, (2) the complexity of carrying out interventions amidst complex exposures of exposures changing over the course of the study and the often uncontrollable social and economic influences often muddies the research question being asked, and this can lead to a preponderance of negative or inconclusive findings in the literature (3) the most natural measures that circumvent the problems associated with using morbidity as an outcome for intervention research are related to productivity, and these measures have the potential to backfire even if the intervention is deemed "effective."

In terms of the broader implications of intervention research, there is a potential to imply that the effectiveness of ergonomics is unknown. For example, the laboratory study by Southard et al. (2007) mentioned earlier showed large reduction in biomechanical loading of the shoulder and low-back by introducing a calf-weighing aid. Given the epidemiological evidence that indicates that such a reduction in loading is beneficial, there should be no reason to seek epidemiologic evidence for this particular difficult to study case, or in similar cases. As researchers in ergonomics, we are perhaps too quick to suggest further research is needed when in fact we have sufficient evidence. Furthermore, the additional scrutiny we bring to our field is not required, for example, by the Total Quality Management (TQM) movement. Imagine how much less progress the quality movement would have made if it were subject to the same scrutiny. Just as production engineers are willing to accept small (i.e., continuous) improvements in quality that yield large advances over time, they should expect no more from ergonomists who often are left to make small incremental improvements in working conditions.

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