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Effect of ergonomics training on agreement between expert and non-expert ratings of the potential for musculoskeletal harm in manufacturing tasks

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Abstract

Objective: Evaluate the effect of ergonomics training on non-ergonomists' ability to recognize and characterize the potential for musculoskeletal harm in manufacturing tasks.

Methods: Ergonomics training was delivered to members of participatory ergonomics (PE) team in a manufacturing facility. Prior to and following training, PE team members and the research team rated the potential for musculoskeletal harm for each of 30 tasks. Measures of agreement included Pearson, concordance, and intraclass correlation coefficients.

Results: Measures of agreement generally improved following training. The greatest agreement was observed for ratings of the potential for musculoskeletal harm to the low back. The greatest improvement in agreement was observed for ratings of the potential for musculoskeletal harm to the neck/shoulder.

Conclusions: The training appeared to improve non-experts' ability to identify the potential for musculoskeletal harm.

INTRODUCTION

Occupational exposure to physical risk factors, such as forceful muscular exertions, awkward postures, and highly repetitive activities, has been associated with increased risk of work-related musculoskeletal disorders (MSDs).[1–3] Many employers have adopted participatory ergonomics (PE) methods to guide efforts to control exposure to physical risk factors. The hallmark of PE is the meaningful contributions of workers in both, the identification/analysis of risk factors and the development of controls.[4] Worker participation capitalizes on their knowledge and experience, and may promote acceptance of workplace changes.[5]

Reported benefits of PE interventions include reductions in musculoskeletal symptom prevalence;[6–8] MSD claims rates and claims costs;[7, 9–12]sick leave and absenteeism;[7, 9, 10, 13]and exposure to physical risk factors.[6, 14, 15]The PE framework has also been

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suggested as a viable model for integrating workplace health protection activities with workplace health promotion activities, a core concept of the Total Worker Health™ program of the National Institute for Occupational Safety and Health. In particular, the scope of PE (which has typically focused on physical aspects of the work environment) can be broadened to also address psychosocial and organizational factors that influence worker health and well-being.[16, 17]

Despite considerable acceptance of the PE approach and applicability of PE to the Total Worker Health™ paradigm, only one previous study was identified that empirically examined the ability of non-ergonomists to learn and apply newly-acquired knowledge and skills within a PE framework.[18] While the results suggested that ergonomics training can lead to improved working conditions, the participants were college students without prior industrial experience. Since some members of a PE team in a real-world setting are experienced workers intimately familiar with industrial processes, some inherent baseline understanding of ergonomics can be expected, even if only informal or anecdotal. To better characterize the value of PE, the specific objective of this study was to evaluate the effect of ergonomics training (delivered as a component of a PE intervention) on non-ergonomists' ability to characterize the potential for musculoskeletal harm in manufacturing tasks.

METHODS

We implemented a PE intervention at a manufacturing facility in Iowa. The facility manufactures vinyl-sided window assemblies for residential construction applications. The facility employs 250 to 400 production workers, depending on seasonal variation in product demand. Most workers perform cyclic, light assembly tasks (mean cycle time ~ 65 sec.) involving manual manipulation of parts, use of powered and non-powered hand tools, and some lifting. The Institutional Review Board at the University of Iowa approved all study procedures

Description of the Training Program

The training component of the PE intervention included two distinct activities: 1) *ergonomics process training*, and 2) *support meetings*. The purpose of the ergonomics process training was to provide relevant, practical information on how to create an ergonomics process within their organizational structure. Content included (a) didactic instruction in musculoskeletal anatomy, physical risk factors, dimensions of exposure, and exposure-effect relationships; (b) instruction in the use of formal exposure assessment instruments (*e.g.*, the Strain Index,[19] the Rapid Entire Body Assessment,[20] and the NIOSH Lifting Equation[21]); (c) hands-on, team-based assessments of tasks performed at the facility; (d) discussion of ergonomics process implementation, with the goal of developing the framework of a strategic plan; (e) examples of the development, implementation, and evaluation of controls; and (f) cost-benefit analyses. The ergonomics process training was delivered by a Certified Professional Ergonomist (NF) over two one-half day workshops.

The purpose of the support meetings was to reinforce training; refine the ergonomics process implementation plan; prioritize development and implementation of controls; discuss control options with PE team members, management, and affected workers; and discuss issues related to workplace ergonomics. Research team members met with the PE team for two hours once per month for one year following the ergonomics process training.

Composition of the PE Team

The PE team included the facility's safety manager, two additional safety personnel, the production manager, the human resources manager, a representative from maintenance, and three production employees (n = 9 from the facility). The general manager served as an ex-officio member of the PE team, but did not contribute data to the current analyses.

Study Procedures

Our evaluation of training effectiveness was based on pre- and post-training agreement between the research team's consensus rating and the PE team's median rating of the potential for musculoskeletal harm associated with specific production tasks. Furthermore, we evaluated pre- and post-training inter-rater agreement between the PE team members' ratings.

Prior to the ergonomics process training, we randomly selected 30 cyclic production tasks and obtained representative 10-minute video recordings of each task (or a minimum of five cycles). For each task, a separate worker was filmed and recordings were obtained simultaneously of the frontal and sagittal planes.

During a meeting convened one week prior to the ergonomics process training, each PE team member viewed each task video and provided his/her ratings of the potential for low back, neck/shoulder, elbow, and hand/wrist musculoskeletal harm on 10-cm visual analog scales (VAS) provided by the investigators. For the upper extremity, ratings were made only for the body side clearly within the sagittal plane camera field of view. Employees at the facility referred to the potential for musculoskeletal harm as an "ergonomic hazard." Therefore, we used descriptive anchors on the VAS scales to reflect such informal terminology. A VAS rating of 0 cm was used to indicate "no ergonomic hazard" and a VAS rating of 10 cm was used to indicate a "very harmful ergonomic hazard." The PE team members were instructed to complete the scales independently and to not communicate while the task videos were played. No identifying information (e.g., PE team member name or job title) was collected with the VAS rating scales. Prior to this meeting, the research team viewed the same video recordings and rated (by consensus) each of the 30 tasks using identical scales.

After the ergonomics process training and one year of monthly support meetings, and with procedures identical to those used just before the ergonomics process training, the research team and the PE team again completed VAS ratings for a second set of 30 randomly-selected cyclic production tasks.

Statistical Analyses

During the year following the ergonomics process training, four of the original nine PE team members left the facility due to reassignment or termination. Therefore, the post-training

VAS ratings completed by the five remaining members of the original PE team were used for the current analyses.

For each task and body region, we computed the median of the PE team members' VAS ratings. We then calculated, for each body region separately, Pearson correlation coefficients between the PE team's median VAS rating and the research team's consensus VAS rating for the set of 30 task videos obtained prior to the ergonomics process training (r_{pre}). Similarly, we calculated Pearson correlation coefficients between the PE team's median VAS rating and the research team's consensus VAS rating from the for the set of 30 task videos obtained following the ergonomics process training and one year of support meetings (r_{post}). The one-sample t-test for a correlation coefficient was used to test the null hypotheses that $r_{pre} = 0$ and $r_{post} = 0$. Fisher's z-transformation was used to estimate 95% confidence intervals for the Pearson correlation coefficients.[22] We also used Fisher's z-test for comparing two correlation coefficients to test the null hypothesis that $r_{pre} = r_{post}$. Since we expected training to improve agreement in VAS ratings between the PE team and the research team, this test was one-sided (*i.e.*, the alternative hypothesis was $r_{post} > r_{pre}$).

We also estimated the pre- and post-training concordance between the PE team's median VAS ratings and the research team's consensus VAS ratings by computing the concordance correlation coefficient (P_c).[23] In contrast to the Pearson correlation coefficient, P_c incorporates corrections for shifts of the linear relationship away from the ideal model (*i.e.*, least-squares linear regression slope = 1.0 and offset = 0.0). Methods described in Lin[23] were used to estimate 95% confidence intervals for the concordance correlation coefficients ($P_{c\text{-}pre}$ and $P_{c\text{-}post}$). Fisher's z-test for comparing two correlation coefficients was used to test the null hypothesis that $P_{c\text{-}pre} = P_{c\text{-}post}$. As above, this test was one sided and separate analyses were performed for each body region.

Finally, the intraclass correlation coefficient (ICC; two-way, random effects model with absolute agreement) was used to estimate the pre- and post-training agreement in the VAS ratings among PE team members. Confidence limits and tests of significance (null hypothesis: ICC = 0) for the pre- and post-training ICC estimates were calculated.[24] Because (1) post-training VAS ratings were available for only five of the original nine PE team members and (2) we did not collect identifying information with the VAS scales, we examined the possibility that a difference between the pre- and post-training ICCs was an artifact of the five remaining PE team members and not a training effect. Specifically, in addition to the pre-training ICC for all nine original PE team members, we estimated the distribution (mean, sd) of the pre-training ICC for all possible combinations of five original PE team members.

Statistical procedures were performed using Microsoft Excel (version 2010, Microsoft Co., Redmond, WA) and SPSS (version 21, IBM Co., Armonk, NY).

RESULTS

In general, measures of agreement between the PE team's median VAS ratings and the research team's consensus VAS ratings were improved following the ergonomics process training and one year of support meetings (Table 1). The largest improvements were observed for the neck/shoulder region (r_{pre} = .13 vs. r_{post} = .46; $P_{c\text{-}pre}$ = .07 vs $P_{c\text{-}post}$ = .36). However, no post-training agreement value was statistically significantly different than its corresponding pre-training agreement value.

For the low back, a small decrease was observed for the post-training Pearson correlation compared to the pre-training Pearson correlation while a small increase was observed for the post-training concordance correlation compared to the pre-training concordance correlation. In this case, the improvement in the post-training concordance correlation was the result of a reduced offset (*i.e.*, smaller intercept) of the least-squares regression line (Figure 1).

The ICCs of the VAS ratings among the PE team members also improved following the ergonomics process training and one year of support meetings. Prior to the training, only the ICC of the VAS ratings of the potential for musculoskeletal harm to the low back was significantly greater than zero. Following training, all ICC estimates were significantly greater than zero. Inspection of Table 1 shows that for the elbows, the 95% confidence intervals around the pre- and post-training ICCs did not overlap, suggesting an improvement not likely due to chance.

The distributions (mean, sd) of the pre-training ICCs for all possible combinations of five PE team members were, .16 (.06) for the low back, .04 (.07) for the neck/shoulder, −.06 (.06) for the elbow, and .02 (.08) for the hand/wrist. For all body areas except the low back, the estimate of the post-training ICCs from the five remaining original PE team members exceeded the mean of the distribution of pre-training ICC estimates for all possible combinations of five PE team members by more than one standard deviation.

DISCUSSION

Considerable methodological heterogeneity is apparent in available literature describing the delivery and evaluation of ergonomics training, in general, and PE interventions, in particular.[25, 26] Several studies report evidence of training effectiveness as improvements of scores on tests of knowledge about physical risk factors, the design of workspaces using ergonomics principles, and other ergonomics-related constructs.[27–29] In contrast, we evaluated a PE team's ability to characterize by observation the potential for musculoskeletal harm, using a process based on a conceptual understanding of ergonomics rather than the rote application of any particular formal exposure assessment instrument. In general, the agreement in VAS ratings of the potential for musculoskeletal harm to the low back, neck/shoulder, elbows, and hand/wrist improved following training activities, although the observed effects were modest in size.

The agreement (Pearson and concordance) between the PE team's median VAS ratings and the research team's consensus VAS ratings was highest for the low back for both the pre- and post-training analyses. Because we did not instruct PE team members to focus on physical risk factors (*e.g.*, posture, force, and repetition) when completing the VAS ratings, we are unable to evaluate specific drivers of the observed results. However, discussion of the results with the PE team suggested several circumstances unique to the facility that may have contributed to this result. Specifically, many of the production tasks involve manual handling of products weighing up to 100 pounds and a facility policy requires team lifts of more than 51 pounds. Furthermore, employees receive a brief orientation to ergonomics upon hire and complete a 30-minute web-based ergonomics training module annually. The orientation and web-based materials contain substantial information about lifting biomechanics. Therefore, the training may not have increased knowledge about factors associated with low back musculoskeletal outcomes to the same extent as knowledge about factors associated with neck/shoulder, elbow, or hand/wrist musculoskeletal outcomes.

Improvement in the ICCs of VAS ratings suggests that the training was at least partially effective in transferring knowledge to PE team members. Estimates of the ICC depend strongly on the specific model (*e.g.*, two-way, random effects vs. two-way, mixed effects) and type (absolute agreement vs. consistency) selected.[30] The ICC model we used treated the PE team members as a random sample of a larger population of similar individuals.

The results of this study should be interpreted cautiously. The ergonomics process training and support meetings appeared to improve the PE team's ability to characterize the potential for musculoskeletal harm over a one-year time-frame. However, the effectiveness and impact of the PE intervention over a longer time period have not been evaluated. The loss of four original PE team members during the year following the ergonomics process training affected our analytical strategy. However, negative long-term effects of PE team member turnover have been minimized through adoption of a strategic plan to guide ongoing intervention activities, which includes provisions for maintaining "institutional memory" of ergonomics.

The PE intervention is a component of an ongoing study of the combined effects of PE and workplace health promotion on exposure to physical risk factors, musculoskeletal symptom prevalence, musculoskeletal injury rate, workers' compensation claims costs, health insurance costs, and indicators of chronic disease risk (e.g., hypertension, obesity, cholesterol). The health promotion component uses motivational interviewing to encourage health behavior change and a participatory approach to implement facility-wide wellness activities.

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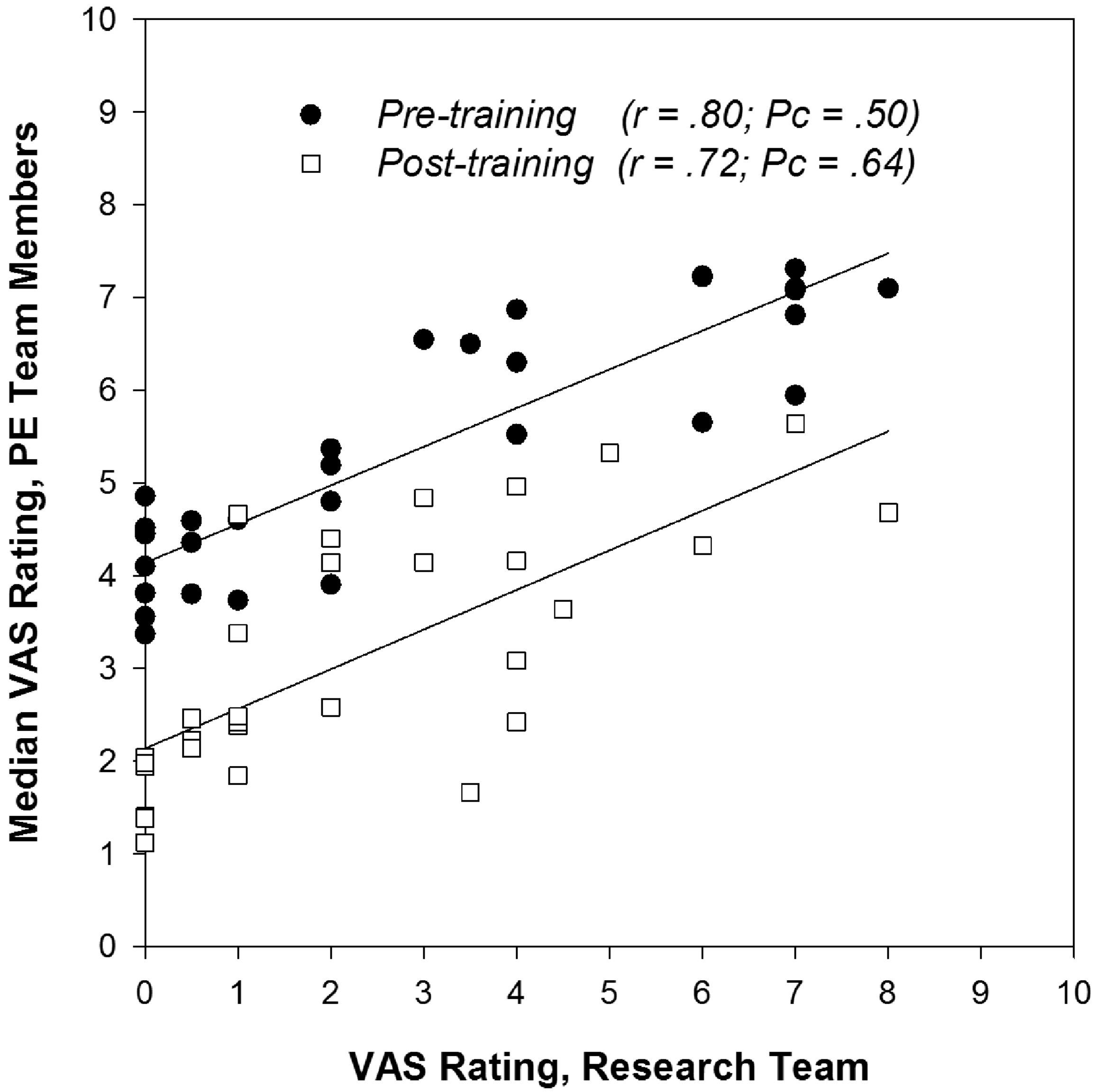

Figure 1:

Pre-training and post-training VAS ratings of the potential for musculoskeletal harm to the low back; *r* = Pearson correlation coefficient, P_c = concordance correlation coefficient.

Table 1:

Pre-training and post-training Pearson (*r*), concordance (P_c), and intraclass correlation (ICC) coefficients, by body region. CI = 95% confidence interval.

	Pre-training		Post-training		Pre/post comparison
	estimate [CI]	**p(1)**	**estimate [CI]**	**p(1)**	**p(2)**
Low Back					
r	.80 [.62,.90]	<.01	.72 [.49,.86]	<.01	.24
P_c	.50 [.31..65]	<.01	.64 [.41,.79]	<.01	.22
ICC	.16 [.07,.32]	<.01	.21 [.06,.25]	<.01	-
Neck/shoulder					
r	.13 [−.25,.46]	.25	.46 [.12,.70]	<.01	.09
P_c	.07 [−.14,.28]	.36	.36 [.10,.57]	.03	.13
ICC	.05 [−.01,.15]	.07	.15 [.03,.33]	<.01	-
Elbow					
r	.50 [.18,.73]	<.01	.50 [.18,.73]	<.01	.96
P_c	.29 [.10,.46]	.06	.42 [.15,.64]	.01	.29
ICC	−.03 [−.06,.03]	.87	.20 [.06,.39]	<.01	-
Hand/wrist					
r	.55 [.24,.76]	<.01	.61 [.32,.79]	<.01	.37
P_c	.47 [.21,.67]	<.01	.58 [.31,.77]	<.01	.29
ICC	.02 [−.03,.11]	.26	.27 [.09,.48]	<.01	-

(1) For *r* and P_C, results of one-sample t-tests for correlation coefficients. For ICC, results of F-tests as described in Shrout and Fleiss.[37]

(2) Results of Fisher's z-test for comparing two correlation coefficients.