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Case Studies

Ergonomic Intervention: A Case Study in a Mass Production Environment

Dawn Tharr, Column Editor

Reported by Cheryl Fairfield Estill and Leslie A. MacDonald

Household appliance manufacturing involves manually intensive parts assembly performed at a fixed work pace that is governed by assembly line speed. The U.S. Bureau of Labor Statistics reported that the household appliance industry was the twelfth highest for musculoskeletal disorders (MSDs), with 268 cases per 10,000 workers.[1] Likewise, the Australian domestic appliance industry was one of the six highest industries for risk of repetitive trauma syndromes.[2] Kaplan and Knutson[3] found that women employed in the household appliance industry in Wisconsin incurred 80 percent of the incidence of repeated trauma injuries for that industry. While the specific details of assembly and subassembly operations differ among appliance manufacturers, they consist of similar task elements such as parts handling and positioning; wiring; and fastening with power driven screws, rivets, or snap-on parts. Assembly workers typically perform the same task (work cycle) every two minutes or less, depending on the facility and product. Although production workers are often permitted to engage in job rotation on a voluntary basis, job rotation in the industry was generally found to be rare by the National Institute for Occupational Safety and Health (NIOSH) researchers. In addition, unadjustable workstation features and poor layout have been found to result in worker exposure to physical stressors in the household appliance industry.[4,5]

Few studies have examined the cost of musculoskeletal injuries, or the cost savings from production changes to prevent them. Riel and Imbeau[6] suggest a system of determining insurance-related, work-related, and perturbation-related (lost time, absenteeism, job reassignments, etc.) costs. These costs are assigned to departments or processes for more accurate decision making. Hensley[7] and Alexander[8] have similar suggestions; they recommend collecting the following data: employment history for the job, including worker's compensation and medical expenses, work-hour savings from the new process, supervisor's time dealing with a high turnover job, and product quality costs from less skilled workers. Oxenburgh[9] proposed a system to determine the payback period for an intervention, based on cost data in four areas: productive hours worked, wage and salary costs, turnover and training costs, and productivity losses. Oxenburgh reported that, using his method, most ergonomic interventions had a payback period of less than one year (frequently six months).

This case study examined the use of estimated future costs associated with upper limb musculoskeletal disorders in the procurement justification for equipment to mechanize a manual task with high physical upper extremity stressors. In addition, the effect of the new mechanized operation on workers' exposure to physical stressors and musculoskeletal symptom prevalence was examined. Workers' assessments of the mechanized task were obtained to provide information about possible unintended consequences of the process change, and to serve as a proxy measure for the likely long-term adoption of this change.

Intervention and Costs

While production was 250 units per day at the pre-intervention assessment, future production estimates were 450 units per day in anticipation of a favorable market for this new appliance. This increase in production was expected to result in a production bottleneck at the bellows task.

To ease this bottleneck, and to reduce workers' exposure to manual stressors associated with the task, the firm sought to purchase specialized equipment to mechanize installation of the bellows. This assembly line was too new (less than 6 months in operation) for the engineer to retrieve information on injury or employment history associated with this assembly task as directed by researchers.[6–9] There were no turnover rates or workers' compensation claims yet associated with this task.

The cost of the bellows machine was $198,000. It was estimated that the machine would provide 66.24 seconds per unit of labor savings. For 450 units, the labor savings were valued at $52,000 per year, for a four-year payback. The firm required a payback period of two to three years for new equipment purchases. Thus, cost justifications involving labor savings alone were not adequate to obtain purchase approval.

Further cost justification for the equipment expenditure was sought by the engineer, based on the cost associated with the workers' future musculoskeletal injury risk. The engineer at the plant who was responsible for the project performed the procurement justification. An estimated 18 workers were determined by the engineer to be required to work in the production cell at the targeted production rate (450 units/day). Since the engineer knew the job had physical stressors, he assumed that those factors were similar to those reported in

Silverstein et al.[10] Therefore, each worker was estimated to have a 10.9 percent chance of developing tendinitis, and a 5.6 percent chance of developing carpal tunnel syndrome, with a cost of $10,000 for each case.[11] The injury costs were projected by the plant engineer to provide an additional future savings of $29,700 per year, for a total savings of $81,700 per year when combined with labor savings (2- to 4-year payback). There were some problems with the plant engineer's justification. Due to the exposure conditions present in the manual bellows operation, he assumed that the health risks for workers were similar to those reported by Silverstein,[10] and he did not account for the occurrence of job rotation, which would have reduced the total task time per worker to only 1/10 of each day.

TABLE I
Pre-intervention bellows cell job descriptions (in order of rotation)

Job number	Description
22	Manual bellows installation; attach bellows and spring to front tub shell
23b	Install 11 or 12 screws to attach front and rear shells
19	Use press to install ball bearing and shaft seal into drive hub
20	Install vanes inside stainless steel drum assembly and apply grease
23a	Install 11 or 12 screws to attach front and rear shells
24	Place weights "A" and "B" on front shell
26	Secure counterweights to front shell and tighten lock nuts
27	Attach motor to tub assembly; attach drive pulley to drive shaft and attach belt
28	Weigh and attach weight "D" to rear shell; assemble bolts to rear shell; secure drive pulley to spider shaft
29	Use manipulator to move the tub assembly into the cabinet; attach five fasteners to console
30	Attach control mounting bracket to cabinet; put spring retainers into cabinet
25	Put weight "C" on front shell and weigh weight "B"
21	Inspect bellows collar and repair flash

Background

This study was conducted at a household laundry equipment assembly plant located in the central United States. The study focused on a task involving the installation of a bellows, a distinct job task within a production cell of a "horizontal axis" washing machine assembly line. Data collection for the pre-intervention assessment was performed in March 1997. New specialty equipment was installed in October 1997, and a post-intervention survey was conducted in August 1999.

Work Organization

Unlike conventional assembly lines, work on this washing machine line was organized according to a cellular, or team-based, approach to production. Hourly job rotation among workstations in the production cell was mandated by company policy. Workers assigned to the bellows production cell were tasked with building the washer tub subassembly.

During the pre-intervention assessment, 13 workers rotated every hour onto 13 workstations (see Table I) in the bellows cell. Each worker in the bellows cell spent one hour assigned to the bellows task every other day (Table I, Job #22), representing eight percent of his or her total work time. Cycle time for all production cell tasks was 105 seconds, and production volume was 250 washing machine units per day. Employment was eight hours per day with one shift in operation.

The bellows is a flexible rubber gasket that is attached to the front tub shell to keep water from leaking through the door of the washing machine unit. At the pre-intervention assessment, the bellows was attached to the tub manually. Manual assembly required the worker to lift the front shell of the plastic tub onto a rotating fixture, attach the bellows to the tub, and then position the spring around the tub assembly (see Figure 1). Attaching the bellows required workers to use a sustained pinch grip to position and align the rubber bellows around the rim of the tub opening, and to repeatedly push the bellows over fastener tabs with their fingertips.

Seven months after the pre-intervention assessment, specialty equipment was introduced into production to mechanize the bellows installation. The redesigned bellows task required the worker to load the tub and bellows gasket into the machine, press activation buttons, and then unload the assembly (see Figure 2). During the post-intervention assessment, seven workers rotated every hour onto seven workstations (see Table II). Each worker in the bellows cell spent one hour assigned to the bellows task every day, representing 14 percent of his or her total work time. Compared to the pre-intervention period, cycle time

FIGURE 1
Manual bellows installation.

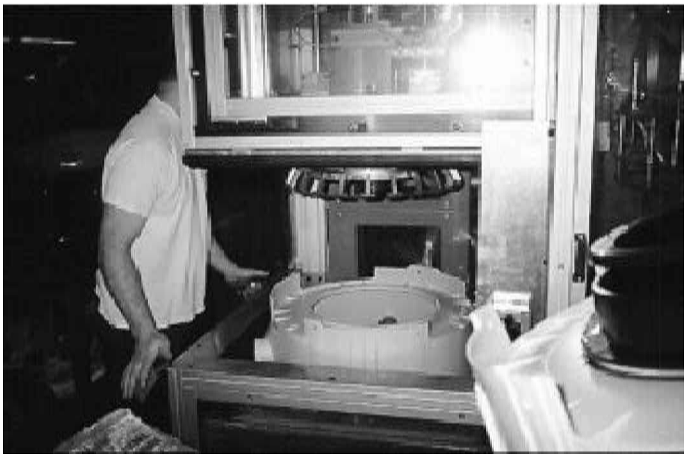

FIGURE 2
Employee operating the automatic bellows installation machine.

was reduced by more than one-third, to 33 seconds, and production volume was increased more than threefold to 800 washing machine units per day. To meet production targets, work hours were increased to 10 hours per day during weekdays, and 8 hours on Saturdays, for one work shift. A local labor shortage prevented the implementation of a second shift to help meet production targets.

The dramatic changes in production capacity during the study period are summarized in Table III. The original 13 job tasks within the bellows cell before mechanization were divided into 31 job tasks that were redistributed among a total of three production cells. During the post-intervention assessment, each worker assigned to the bellows cell rotated among fewer job tasks, and performed each job twice as often.

Similar changes in job content occurred throughout the entire assembly line during the study period. About half of the workers who were no longer working on the bellows cell at the post-intervention assessment were still employed on the assembly line. Only one worker from the original bellows cell was remaining at the post-intervention assessment (the least senior worker from the pre-intervention assessment became the most senior). These production changes occurred slowly but steadily over the 29-month study period.[12]

TABLE II
Post-intervention bellows cell job descriptions (in order of rotation)

Job number[A]	Description
22	Automatic bellows machine operator
21	Inspect bellows and tub shell; assist bellows operator; stock parts; fill in for other employees during breaks
20a	Transfer drum assembly; install three vanes in drum
18	Insert gasket into channel of rear shell
19a	Install ball bearings into drive hub using bearing press
19b	Place rear tub shell onto fixture and apply grease with manual grease gun
20b	Inspect drum assemblies and place onto rear shell; move assembly to slate track

[A]The job numbers correspond to the similar jobs from the pre-intervention survey.

The mechanized bellows installation was faster than manual assembly by 66 seconds per unit (62%). Despite the increased task efficiency of the mechanized operation, manual bellows installation was still required after equipment installation to ensure an adequate supply of tub subassemblies, due to the large increase in production volume. Figure 3 shows a worker attaching the bellows manually while also operating the machine, completing one manual installation for every eight completed by the machine. As such, the high pinch forces required for manual installation were not eliminated at the post-intervention assessment, but total exposure time to the manual operation was reduced.

Methods

Subjects

At the pre-intervention assessment, all 15 eligible workers participated in the study (13 assembly operators and 2 floaters, who were not assigned to a particular workstation but filled in as needed). At the post-intervention assessment, 8 of 9 eligible workers participated (6 operators and 2 floaters). One worker participated in both surveys. In addition, a short questionnaire was completed at the post-intervention assessment by 17 former and current workers from the bellows cell. Demographics are presented in Table IV.

Task-Related Symptoms and Acceptance of Intervention

A two-page questionnaire was administered to current and former workers of the bellows installation task at the post-intervention assessment. Information was collected for all workers who had performed the bellows installation using both the manual and mechanized methods. The questionnaire included questions based on the following: presence of musculoskeletal task-related symptoms (no/yes, multiple sites); overall physical exertion required; and ability to keep up with production. Additionally,

TABLE III
Production information for bellows cell

	Pre-intervention	Post-intervention
Number of shifts in operation	1	1
Number of units produced	250 units/day	800 units/day
Average time for worker to perform task on one unit	105 s/unit	33 s/unit
Number of workstations in cell	13	7
Rotation schedule	Each hour	Each hour
Number of workers in the bellows cell	13–rotate; 2–floaters	7–rotate; 2–floaters
Schedule	8-hr work days (7:00–3:30); no Saturdays	10-hr work days (6:30–5:00); 8-hr Saturdays
Total number of employees on the assembly line	73	155

these workers were asked to list three things they liked and three they disliked about the bellows machine. Results were matched by participant for those who had used both methods (n = 11). A sign test[13] was used to determine if there was a difference in pain or discomfort at each body location.

Observational Assessment

An observational assessment of workers performing the bellows installation job was conducted before and after the new equipment was installed, in order to characterize worker exposure to physical stressors. During the pre-intervention evaluation, a direct observational assessment was performed on 3 of 15 workers. For the post-intervention evaluation, a video recording assessment was performed on 2 of 7 workers. The observational assessment consisted of a risk factor checklist,[14] which was completed by a contract ergonomist during pre-intervention, and by one of the authors during the post-intervention assessment. Workers were chosen for the observational assessment by convenience; any worker available was selected. The following exposure conditions were recorded on the checklist: peak back flexion, extension, twist, and lateral deviation; peak neck flexion, extension, twist, and lateral deviation; peak shoulder flexion, extension, and abduction; forearm pronation and supination; peak wrist flexion, extension, and radial and ulnar deviation; hand and lateral pinch; contact stress (with sharp surface) of the finger, palm, wrist, elbow, or armpit; and finger wrap worn.

FIGURE 3
While automatic bellows machine is running, employee is putting a spring on the bellows that he has manually attached to the tub shell.

Results

Task-Related Symptoms and Acceptance of Intervention

The task-induced pain of the fingers was significantly reduced when using the mechanized bellows operation compared to manual operation (sign test, $p = 0.004$). Other body locations were not statistically different (see Table V). The use of the automatic bellows machine slightly reduced both the relative amount of time that the workers had difficulty keeping up with production and the workers' ratings of physical exertion, but neither was significant (see Table VI).

The workers who completed the questionnaire indicated 25 things they liked and 30 things they disliked about the mechanized bellows operation (see Table VII). The attribute the workers liked most about the mechanized bellows operation was that it allowed them to perform the task with less physical pain or injury. The following statements were made: "It's easy on your body;" "Saves on wrist injuries;" "Easier on your wrists;" and "Lets you rest your hands." Negative comments included mention of the machine breaking down often, not being able to keep up with the current production rate, and sometimes losing its springs. None of the negative comments mentioned any physical discomforts.

TABLE IV
Subjects' mean age, gender, anthropometric characteristics, and job duration

Subject	Age (yr)	Height (m)	Weight (kg)	Employment (yr) Plant	Employment (yr) Current job	Gender (%)	Part. rate (%)
Bellows cell workers at pre-intervention (n = 15)							
Mean	38.7	1.77	86.6[A]	10.2	0.6	80 male; 20 female	100
S.D.	8.0	0.09	19.0	3.5	0.3		
Bellows cell workers at post-intervention (n = 8)							
Mean	34.2	1.77	91.1	4.2	1.5	88 male; 12 female	88.9
S.D.	8.0	0.06	16.8	2.7	1.6		
Bellows questionnaire participants at post-intervention (n = 17)							
Mean	35.6	1.71	90.7	7.2	1.7	59 male; 41 female	68.0[B]
S.D.	6.8	0.12	21.3	6.3	1.6		

[A]Only 14 participants reported their weight.
[B]The denominator was combined from pre-intervention and post-intervention; others could have been employed in the interim.

TABLE V
Pain or discomfort due to bellows task only, according to workers familiar with both methods (at post-intervention)

Body location	Number of participants indicating pain or discomfort (n = 11) Manual	Automatic	p value
Finger(s)[A]	10	1	0.004
Hand/wrist	7	3	0.125
Elbow	2	1	1.000
Shoulder	3	1	0.500
Neck	4	2	0.500
Upper back	3	3	1.000
Lower back	3	3	1.000

[A]The sign test was used to determine if there was a difference between pairs. The amount of pain at the fingers was significantly less when participants used the mechanized bellows operation (sign test, p = 0.004).

TABLE VI
Acceptance of intervention from bellows questionnaire collected at post-intervention

Question	Rating mean (S.D.) Manual	Automatic
How often did you have trouble keeping up with production? (0 = never; 3 = all the time)	1.9 (0.94)	1.6 (0.85)
Rate the average overall physical effort level that was required to perform the bellows installation job. (0 = very light; 5 = very hard)	3.3 (1.1)	3.0 (1.1)

Observational Assessment

Physical stressors that were reduced from the pre- to post-intervention assessment (see Table VIII) include the following: number of pinch grips per cycle; peak back flexion, lateral deviation, and twist; peak neck flexion and lateral deviation; and presence of finger wrap.

Manual installation required approximately 28 exertions of 2.7 kg (6.0 lbs) (S.D. = 0.4 kg [0.8 lb], n = 10) with a pinch grip (average of one exertion every four seconds). A force gauge (Model FDV50, Wagner Digital Force Gauge, Greenwich, CT) was used by one worker to simulate the bellows attachment, with 10 repetitions. Pinch gripping was reduced but not eliminated by the mechanized bellows operation because workers continued to perform the manual bellows installation (though on a more limited basis) to ensure an adequate supply of tub subassemblies. Pinch grips were reduced from about one every four seconds to one every nine seconds, and the wearing of finger wraps was reduced among those workers observed.

Extreme back flexion, twisting, and lateral deviation was reduced. All three observed workers flexed and laterally deviated their backs at least 20 degrees during each cycle at pre-intervention, whereas neither worker flexed or laterally deviated his back greater than 20 degrees during the post-intervention assessment. Back twisting was also reduced from two of three workers twisting 20 degrees or more during pre-intervention to twisting less than 20 degrees during the post-intervention assessment. Neck flexion and lateral deviation were reduced for most workers observed. Few differences were found for the other physical stressors

Discussion

Workers' comments about the mechanized bellows operation suggest that this process change has been accepted. The use of the machine significantly reduced the number of workers who experienced task-specific pain in their fingers. Additionally, the comments indicate that workers attributed the machine

TABLE VII
Participant responses about the mechanized bellows operation

	Number of participants giving response	Number of responses
25 Positive responses (11 workers)		
Puts the bellows on	6	7
Less physical pain or injuries (wrist, fingers, and hands mentioned)	4	6
Installs the spring in addition to the bellows	4	5
Faster than manual	4	4
Nice work flow	3	3
30 Negative responses (11 workers)		
Breaks down often	7	9
Can't keep up with production	7	8
The springs sometimes come off	6	6
Other: must operate just right to avoid breakdown; not enough soap; etc.	4	7

to reduced discomfort in their fingers, hands, and wrists. Other comments indicate the workers' dependence on the machine. Pain or discomfort was still reported by workers using the machine. The workers mentioned that the machine often breaks down, has difficulty keeping up, and sometimes loses its springs. These comments point to a quality problem with the machine.

No statistical difference was found for the workers' reported ability to keep up with production, or physical effort, when comparing manual and mechanized bellows operation. The increase in production from the pre- to post-intervention assessment (3.2 times greater), as well as the continuation of manual bellows installation, confounds the comparison. Job content was also reduced, as shown by the decrease in cycle time and the number of workstations through which workers rotated.

The observational assessment showed that the amount of forceful finger pinching was reduced, and workers stopped wearing finger wraps. Forward flexion of the torso was reduced during manual bellows attachment because the height of the workstation was raised. Although workers used their palms to activate the bellows machine, the surface of the buttons was smooth, and the force required was low. Palmar contact stresses were reduced at the post-intervention assessment because a boomerang-shaped attachment that required palmar contact stress was eliminated.

TABLE VIII
Observational assessment comparison[A]

Variable	Pre-intervention (3 workers)	Post-intervention (2 workers)
Hand pinch	Y, Y, Y (25/cycle)	Y, Y (6/cycle)
Peak back flexion	20°–45°, 20°–45°, >45,	N, N
Lateral deviation	all >20°	N, N
Twist	<20°, >20°, >20°	<20°, <20°
Peak neck flexion	>45°, >45°, >45°	20°–45°, 20°–45°
Lateral deviation	<20°, >20°, >20°	<20°, <20°
Finger wrap	Y, Y, N	N, N
Contact stress—palmar	Y, Y, Y	N, N

[A] Y = yes; N = no.

The specialty bellows machine cost $198,000. A labor savings of $52,235 per year was predicted, based on an assumed production rate of 450 units per day. Using the same cost figures, the 800 units per day produced a labor savings of $92,839 per year. Labor savings alone would have been enough to justify the bellows machine had the true future production rate been known.

The predicted savings of $29,700 associated with avoiding future health costs were probably not realized by the company. Although a decline in some of the occupational risk factors was observed, the pinch forces to manually attach the bellows still remained (but at more reasonable frequencies). Also, it has been shown that while workers had less pain in their fingers from the use of the mechanized bellows installation, they still had pain in other body parts. On the other hand, the addition of the mechanized bellows equipment is not alleged to pose any additional physical stressors, and is believed to have avoided some stressors associated with the production increase. For instance, if the machine had not been purchased, the equivalent of 3.2 full-time employees would have been required to manually install the bellows during the post-intervention assessment, requiring each worker to spend about 33 percent of his or her time on this task. This increase in the time spent by each worker probably would have translated into additional health costs for the company.

Some of the difficulties of conducting field-based intervention research was illustrated by the unanticipated dramatic increase in production volume that occurred during the 29-month study period. Other changes affecting the comparisons included the self-selection of pre-intervention workers into other jobs, resulting in an almost entirely new group of workers at the post-intervention assessment. These changes made it difficult to attribute reductions in physical stressors and symptoms to the new equipment. Shorter follow-up periods for pre- and post-intervention comparisons could forestall some of the difficulties encountered in this study.

Conclusion

The specialty equipment installed for the mechanization of the bellows installation was accepted by its users, reduced exposure to forceful pinching, and decreased the amount of finger pain. The extreme rise in production, as well as the continued need for manual bellows installation, made it unfeasible to determine the reduction in MSDs due to the mechanization of this task. Organizational changes implemented during the study period reduced job content and increased the total time assigned to the bellows task.

Future injury costs are difficult to compute because data needed are typically unavailable. If future injury costs are calculated to justify equipment purchases, these data should be provisional. Information on the risks and costs associated with MSDs should be compiled and disseminated to engineers in industry for the justification of equipment.

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