treatment groups and for both the fixed effects and random effects models. Thus, at least in the time frame of our study, there is no evidence that the productivity gains are short-lived.

IV. HEALTH-MEDIATED EFFECTS MODEL

This section of the paper analyzes the effects of the two interventions on the SF-36 pain score and the relationship between the SF-36 pain score and production. In the first step, pain scores are modeled as a function of gender, age, tenure at the agency, disability status, years of education, job characteristics (collector and level), treatment group assignment (chair-with-training and training-only), and treatment group assignments interacted with a post-intervention dummy variable using fixed effects and random effects estimates. The results of these estimations are found in Table 5.

The pain regressions in Table 5 follow the same form as the productivity regressions in Table 4, using the same dependent variables and the same panel regression techniques. As before, preexisting differences in pain scores between groups are reflected in the "chair with training" and "training only" dummy variables, while the effect of the interventions on pain are summarized by the "chair-with-training × post-intervention" and "training × post-intervention" variables. This baseline model excludes the "post-intervention" stand-alone variable because there was no expectation that pain scores would change in the control group post-intervention. The coefficient estimates from this baseline model in columns 1 and 3 indicate that the chair-with-training intervention reduced pain by 5.95 to 6.23 points, and the training-only intervention reduced pain by 1.83 to 2.12 points, depending on whether random or fixed effects are used (recall that higher scores of the SF-36 score correspond to lower levels of pain). In the case of the chair-with-training intervention, both estimates are significant at the 5 percent level. In the case of the training-only intervention, neither estimate is statistically significant.

An alternative specification including a stand-alone "post-intervention" dummy variable is found in columns 2 and 4. This specification allows for the possibility of a secular trend in pain scores over time, which could, in theory, confound the estimates of the interventions' impact on pain. The coefficient point estimates on the "post-intervention" stand-alone variable indicate an unexpected, moderate drift in pain scores among the controls. Controlling for post-intervention changes in pain scores among those who did not receive any intervention reduces the estimated impact of the chair-with-training and training-only interventions by 2 points, suggesting caution when interpreting the "chair-with-training × post-intervention" and "training only × post-intervention" coefficients in the baseline model. Nevertheless, one cannot rule out the possibility that the observed change in post-intervention pain among the controls may be due to random noise given that the coefficient estimates on the "post-intervention" stand-alone variable are not statistically significant. A larger sample would have been necessary to resolve this issue.

Table 6 contains the coefficient estimates and standard errors of a regression of tax collections per effective workday on the same set of demographic and job characteristic variables as in Table 5, plus pain scores. The estimates found here indicate that a one-point improvement in pain is associated with either a $13.25 or $19.14 increase in production per effective workday depending on whether fixed or random effects were used.

With these numbers in hand, we can calculate the health-mediated effect of the chair-with-training intervention. The health-mediated estimate of the productivity gain derived from the training-only intervention is assumed to be zero, given that there is no statistically significant relationship between the training-only intervention and post-intervention improvements in pain. For simplicity, we limit the discussion here to the fixed effects baseline model in Table 5 (column 1) and the fixed effects model in Table 6 (column 1), although similar numbers can be easily obtained using the numbers from the other regressions. In Table 5, the estimated coefficient indicates that the chair-with-training intervention reduces pain by 6.23 points. In Table 6, a one-point reduction in pain is associated with an increase in tax collections of $19.14 per effective workday. Thus, the health-mediated effect of the chair-with-training intervention is 6.23 × $19.14 = $119.24 per effective workday.

V. LOST WORK TIME

Tables 7 and 8 provide a total effects and health-mediated effects model of the two interventions on monthly hours of sick leave, the measure of absenteeism provided by the firm. The form of these two models is analogous to the total effects and health-mediated effects models of productivity, except that they predict sick leave hours per month rather than sales tax collections per effective workday. An examination of the "chair-with-training × post-intervention" and "training × post-intervention" coefficients in Table 7 reveals that none of the coefficients are quantitatively large (for example, sick hours are reduced by 0.16 hours in Column 1, or 0.02 workdays per month) or statistically significant at a reasonable level. A similar conclusion can be found in Table 8. While the coefficient estimates on the "chair-with-training × post-intervention" and "training × post-intervention" variables are statistically significant, the point estimates imply a relatively trivial change in sick leave hours per month compared to the gains in on-the-job productivity reported in the previous two sections. For instance, the fixed effects estimate implies a 0.04 hours reduction in sick leave hours per month per point of SF-36 pain reduced. This implies a total monthly change of sick leave of 0.04 × 6.23 = 0.25 hours per month.

VI. COST-BENEFIT ANALYSIS

Table 9 summarizes our findings and puts them in context. The average amount (not regression adjusted) of individual collections per effective workday in the 11 months prior to the interventions was $1,993.98. This number will serve as the base value used in our calculations of the percentage increase in production due to the chair-with-training intervention. Our estimate from the health-mediated model of productivity indicates that the chair-with-training intervention led to a $119.24 increase in sales tax collections per effective workday, or a 6 percent increase over the pre-intervention base figure. Our estimate from the total effects model indicates a $353.11 increase in sales tax collections per effective workday, or a 17.7 percent increase over the pre-intervention base figure.

The benefit-to-cost ratio at one year after the intervention is calculated using fixed effects estimates from the baseline model only. A benefit-to-cost ratio greater than one indicates a positive return on investment while a number less than one indicates an economic loss. The chair itself cost $800 per person and the direct costs of the trainers (their time and travel expenses) amounted to $200 per participant. The participants' average hourly wage is $21.49/hour. Thus, the labor costs of the 90-minute training session averaged $21/hour × 1.5 hours = $32 per participant. The intervention benefits include reductions in absenteeism (0) and increases in on-the-job production. Using the more conservative estimate of increased production from the health-mediated model of $119.24 per workday and the administrative data's per-person average of 17.75 effective workdays per month, the average monthly benefit flow is $119.24 × 17.75 = $2,116.51 per month or $2,116.51 × 12 = $25,398.12 per year. Thus, the benefit-to-cost ratio for the chair-with-training intervention is $25,398/($800+$200+$32) = 24.61. In other words, benefits from the chair-with-training intervention are approximately 25 times larger than costs in the first year.

The large size of the benefit-to-cost ratio may reflect political constraints on staffing levels unique to the public sector. It is plausible that state legislatures may understaff departments of revenue due to budget pressures and political concerns, leading to a marginal product of labor that is considerably higher than a sales tax collector's wage. The marginal product of labor in private firms may be much closer to the wage rate. In such cases, the daily benefits of the chair-with-training intervention can be approximated by multiplying the percentage increase on-the-job daily production by the wage rate. The benefit after one year is this number multiplied by the average number of days worked in a month times 12. Using the 6 percent increase in production from the health-mediated model, this "wage replacement" method yields a daily benefit of $21.49/hour × 0.06 × 8 hours = $10.32, which is about 12 times smaller than the benefit estimated previously of $119.24. Taking the wage rate and number of days worked per month from the study above, the benefit-to-cost ratio after the first year would be ($10.32 × 17.75 days per month × 12 months)/($800 + $200 + $32) = 2.13. Thus, the lower productivity gain estimates from the health-mediated model imply that the "chair-with-training intervention" would pay for itself within six months in a firm similar to this agency where the marginal product of labor equaled the wage.

VII. DISCUSSION AND CONCLUSION

The productivity gains associated with the chair-with-training intervention are similar to the gains reported in two other studies. Dainoff (1990) conducted a series of laboratory experiments in which the office productivity of subjects was monitored using different office configurations. He found a 17.5 percent productivity increase in subjects working in an ergonomically optimal setting compared to one which was ergonomically suboptimal, a number which is comparable to the total effects estimate productivity increase (17.7 percent) associated with the chair-with-training intervention. Niemela et al. (2002) report non-experimental evidence that a renovation of a harbor storage facility resulted in a 9 percent post-intervention productivity increase compared to pre-intervention levels. Nevertheless, it is important to consider that prior studies primarily focused on health outcomes and conducted productivity analysis in an opportunistic *post hoc* fashion. In contrast, this study was specifically designed to assess the productivity effects of a well-designed intervention.

Aaras (1994) provides cost-benefit calculations derived from a 12-year, non-experimental field study of a Swedish telephone manufacturer and finds that workplace redesign substantially reduces turnover rates and sick leave absences. By comparison, we find no effect of the interventions on sick leave hours. After 12 years, Aaras calculates that the benefits to the employer were nine times larger than the costs, implying a breakeven point of a little over a year compared to less than six months in this study when the wage replacement method is used. Nevertheless, it is difficult to directly compare the benefit-to-cost ratios derived from Aaras' calculations to our own because of the differences in specific interventions, study time frames, and productivity outcome variables.

There are three important factors to note concerning the calculations of productivity impacts reported. First, the independent calculation of the health-mediated model estimates acts as a type of validation of the total effects estimates. While there are theoretical reasons to expect that the health-mediated effects would be smaller than the total effects estimates, there was no guarantee that the empirical estimates would conform to this theoretical supposition. The fact that two independent methods of calculating the interventions' effects yield internally consistent results provides evidence of the reliability of both sets of estimates. The reverse would be true had the health-mediated estimates been larger than the total effects estimates. Second, about a third (from row E in Table 9, 6.0/17.7 = 0.339) of the total effect of the "chair-with-training intervention" on productivity can be explained by improvements in pain scores alone, leaving aside any improvements in work space utilization, job satisfaction, comfort, or fatigue that may have led to increased production. Third, there are potentially large production gains from an ergonomic intervention, even when the intervention has no effect on lost work time. Previous estimates of the social costs of work-related musculoskeletal disorders (such as back and repetitive strain injuries) have relied mostly on estimates of the dollar value of lost work time associated with such disorders.[3] The results from this study suggest that such calculations of social costs suffer from a substantial downward bias. Furthermore, these results show that ergonomic interventions do not necessarily need to reduce lost work time in order to produce a substantial economic benefit to employers; information that is germane to work environments in which lost work time is low.

Perhaps most importantly, the findings of this study suggest that firms may benefit substantially by improving the seating of their office workers in conjunction with a training program in office ergonomic principles and practices, even if these firms do not have workers who suffer from acute musculoskeletal disorders. In contrast, the training-only benefits are less clear. Not only are the point estimates of such benefits smaller than those of the chair-with-training intervention, albeit in the right directions of reducing pain and enhancing productivity, such estimates are not statistically significant. While the point estimates reported from the total effects estimation results suggest a substantial productivity impact for the training-only intervention, a study with a larger sample size would be needed to provide the statistical power necessary to conclusively show that training alone provides a productivity benefit.

Figure 1

Study Timeline

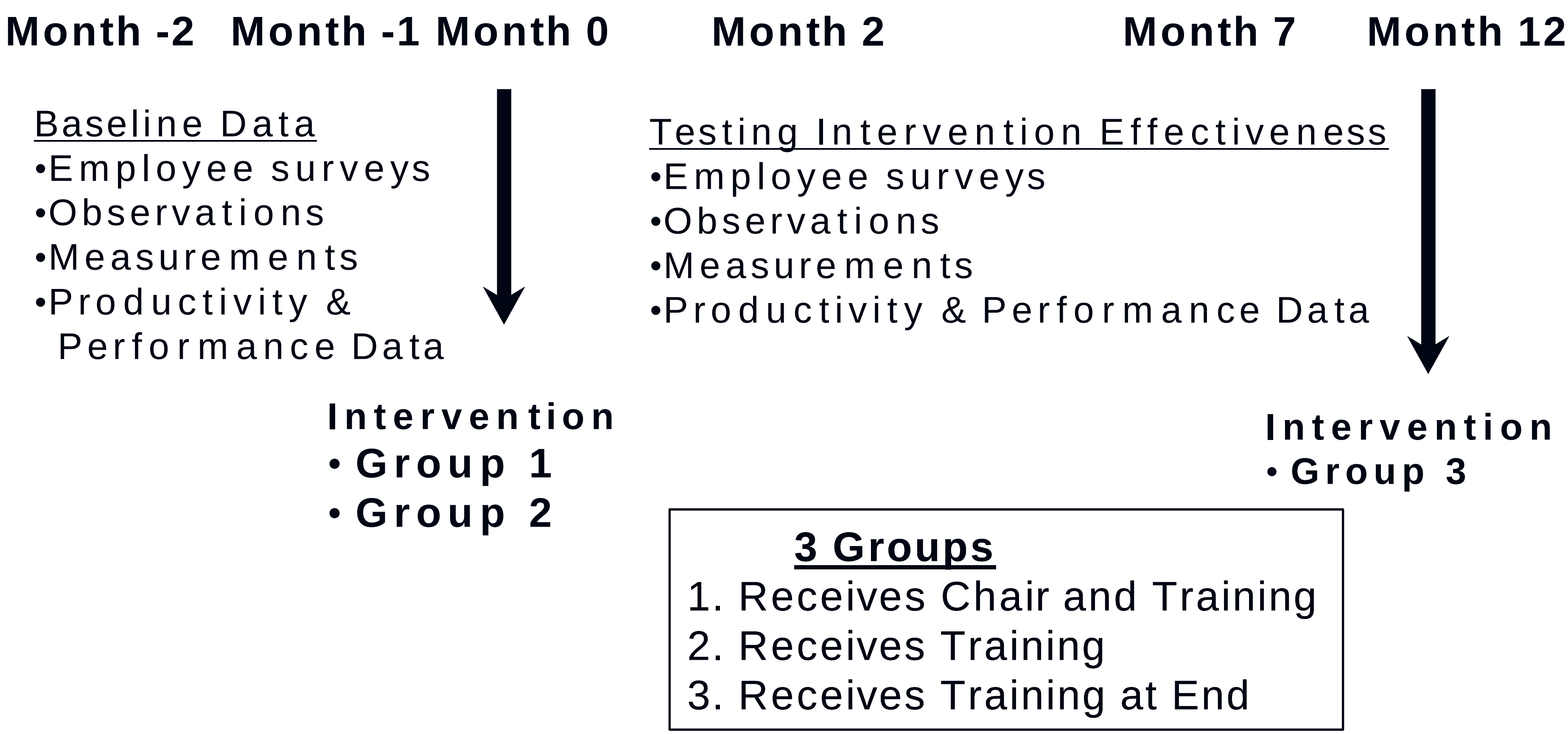

Figure 2

The Model of Change

(from Amick et al. 2002)

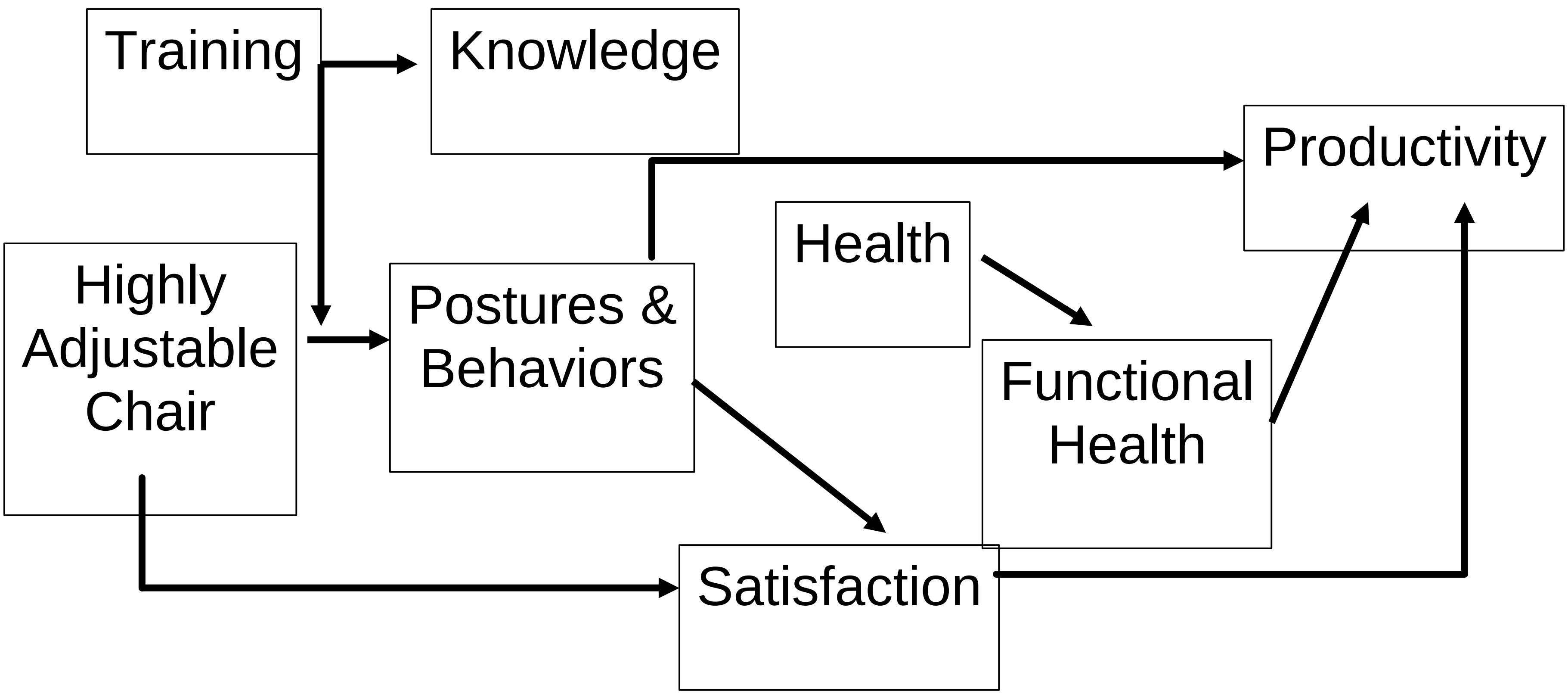

Table 1 Means for Regression Variables (Pre-intervention Data for March and April 2001)

Variable	Total sample	Chair and training	Training only	Control group
Age [a]	47.47	46.77	49.01	46.92
Female [a]	0.58	0.52	0.57	0.69
Tenure [a]	15.88	14.06	16.81	17.65
Disabled [a]	0.11	0.09	0.2	0.03
Years of education [a]	15.03	15.32	15.31	14.25
Collector [a]	0.44	0.47	0.19	0.65
Level [a]	3.28	3.31	3.56	2.93
SF-36 pain score [b]	65.71	66.8	4.66	64.87
Monthly sales tax collected [a]	34509.50	36277.84	22793.71	37394.13
Production per effective day [a]	1940.53	2000.7	1162.94	2144.02
Hours of sick leave [a]	4.69	4.42	4.37	5.45
	(*N*=208)	(*N*=88)	(*N*=61)	(*N*=59)

[a] Means calculated using 11 months of data (July 2000–May 2001).
[b] Means calculated using only 2 survey months (March and April 2001).

Table 2 Means for Regression Variables (Post-intervention Data for July 2001, December 2001, and May 2002)

Variable	Total sample	Chair and training	Training only	Control group
Age [a]	47.47	46.84	48.83	46.98
Female [a]	0.59	0.52	0.57	0.7
Tenure [a]	15.83	13.97	16.71	17.61
Disabled [a]	0.11	0.09	0.2	0.03
Years of education [a]	15.03	15.31	15.32	14.27
Collector [a]	0.45	0.5	0.19	0.64
Level [a]	3.3	3.38	3.54	2.95
SF-36 pain score [b]	69.44	72.38	67.56	66.35
Monthly sales tax collected [a]	34183.67	40098.56	23686.19	34091.47
Production per effective day a	2128.83	2362.64	1306.3	2187.46
Hours of sick leave [a]	4.45	4.23	4.31	4.91
	(*N*=208)	(*N*=88)	(*N*=61)	(*N*=59)

[a] Means calculated using 12 months of data (June 2001–May 2002).
[b] Means calculated using only 3 survey months (July and December 2001, May 2002).

Table 3 The SF-36 Pain Scores of Study Participants and National Norms by Age Group

Age group	National means[a]	DOR means	P-value for test of difference in means
Ages 18–24	80.82	96	0.0321
Ages 25–34	81.35	70.83	0.0006
Ages 35–44	77.06	67.41	0
Ages 45–54	73.12	67.87	0
Ages 55–64	67.51	67.71	0.9053
Ages 65–74	68.49	73.5	0.3467
Ages 75 +	60.88	44.67	0.0475

NOTE: DOR participants, excluding monthly hours worked < 20. Average production per effective day > 50,000, and part-time workers.

[a] National means reported in Ware (1993).

Table 4 Total Effects Model Production per Effective Workday (Production data taken from July 2000 to May 2002)

	Fixed effects	Fixed effects with post-intervention indicator	Random effects	Random effects with post-intervention indicator
Constant	2,463.24**	2,470.40**	–2,164.64	–2,177.92
	(657.09)	(657.57)	(2,437.78)	(2,447.95)
Female	—	—	–258.29	–258.76
			(456.99)	(458.77)
Age	—	—	20.43	20.42
			(27.60)	(27.71)
Tenure	—	—	27.56	27.55
			(27.85)	(27.96)
Disabled	—	—	422.02	423.31
			(722.72)	(725.49)
Education	—	—	186.58	187.01
			(126.87)	(127.36)
Collector	237.93	237.01	1,261.15**	1,256.54**
	(405.92)	(406.00)	(315.59)	(316.07)
Level	–211.75	–217.03	–168.11	–170.37
	(195.08)	(195.77)	(149.05)	(149.56)
Chair and training	—	—	–385.91	–367.07
			(434.33)	(441.89)
Training only	—	—	–803.98	–786.46
			(603.52)	(609.93)
Post-intervention indicator	—	45.46	—	35.63
		(137.74)		(137.64)
Chair-training × post-Intervention	353.11**	307.75	324.44**	288.95
	(134.24)	(192.14)	(134.17)	(192.14)
Training × post-intervention	151.01	105.55	155.69	120.02
	(240.01)	(276.77)	(240.03)	(276.75)
Observations	2502	2502	2502	2502
Overall R^2	0.0125	0.0124	0.1246	0.1243

Standard errors in parentheses; * = significant at 10%; ** = significant at 5%.

Table 5 Health-Mediated Model, Step 1: Effect of Intervention on SF-36 Pain Score
(Health data taken from survey months: March 2001, April 2001, July 2001, December 2001, and May 2002.)

	Fixed effects	Fixed effects with post-intervention indicator	Random effects	Random effects with post-intervention indicator
Constant	62.68**	62.62**	72.10**	70.79**
	(7.02)	(7.02)	(15.42)	(15.41)
Female	—	—	–0.82	–0.79
			(2.73)	(2.72)
Age	—	—	–0.15	–0.15
			(0.16)	(0.16)
Tenure	—	—	0.17	0.17
			(0.17)	(0.17)
Disabled	—	—	–5.54	–5.54
			(3.88)	(3.86)
Education	—	—	–0.11	–0.11
			(0.85)	(0.85)
Collector	7.97	7.72	–4.98**	–5.01**
	(8.13)	(8.12)	(2.47)	(2.46)
Level	–0.09	–0.16	1.36	1.34
	(2.14)	(2.14)	(1.20)	(1.19)
Chair with training	—	—	–0.11	1.18
			(3.19)	(3.38)
Training only	—	—	–1.71	–0.42
			(3.74)	(3.91)
Post-intervention indicator	—	2.48	—	2.18
		(1.96)		(1.95)
Chair-with-training × post-intervention	6.23**	3.75	5.95**	3.77
	(1.48)	(2.45)	(1.46)	(2.44)
Training × post-intervention	1.83	–0.65	2.12	–0.06
	(1.93)	(2.75)	(1.92)	(2.74)
Observations	855	855	855	855
Overall R^2	0.0013	0.0017	0.0538	0.0541

Standard errors in parentheses; * = significant at 10%; ** = significant at 5%.

Table 6 Health-Mediated Model, Step 2: Effect of SF-36 Pain Score on Production per Effective Workday (Health data taken from survey months: March 2001, April 2001, July 2001, December 2001, and May 2002.)

	Fixed effects	Random effects
Constant	727.39	–2,825.24
	(1154.52)	(2,657.94)
Female	—	–262.11
		(492.85)
Age	—	16.70
		(29.98)
Tenure	—	48.35*
		(29.36)
Disabled	—	–52.71
		(795.72)
Education	—	98.18
		(138.33)
Collector	945.86	2,260.05**
	(1,075.64)	(479.31)
Level	–250.17	–194.88
	(337.38)	(198.30)
SF-36 pain score	19.14**	13.25**
	(5.73)	(5.21)
Observations	503	503
R-squared	0.0509	0.1501
Overall R^2		

NOTE: Standard errors in parentheses; * = significant at 10%; ** = significant at 5%.

Table 7 Monthly Hours of Sick Leave (Hours of sick leave taken July 2000 to May 2002.)

	Fixed effects	Fixed effects with post-intervention indicator	Random effects	Random effects with post-intervention indicator
Constant	3.95**	4.06**	9.59**	9.93**
	(1.32)	(1.32)	(2.32)	(2.33)
Female	—	—	0.19	0.19
			(0.41)	(0.41)
Age	—	—	–0.03	–0.03
			(0.02)	(0.02)
Tenure	—	—	–0.03	–0.03
			(0.03)	(0.03)
Disabled	—	—	1.45**	1.45**
			(0.58)	(0.58)
Education	—	—	–0.19	–0.19
			(0.13)	(0.13)
Collector	0.12	0.01	0.34	0.32
	(1.04)	(1.04)	(0.37)	(0.37)
Level	0.18	0.19	–0.14	–0.14
	(0.40)	(0.40)	(0.20)	(0.20)
Chair and training	—	—	–0.49	–0.85
			(0.49)	(0.53)
Training only	—	—	–0.41	–0.76
			(0.57)	(0.60)
Post-intervention indicator	—	–0.68*	—	–0.67*
		(0.36)		(0.36)
Chair-with-training × post-intervention	–0.16	0.52	–0.16	0.51
	(0.29)	(0.47)	(0.29)	(0.46)
Training × post-intervention	–0.02	0.66	0.00	0.67
	(0.36)	(0.51)	(0.36)	(0.51)
Observations	4429	4429	4429	4429
Overall R^2	0.0001	0.0006	0.0146	0.0153

Standard errors in parentheses; * = significant at 10%; ** = significant at 5.

Table 8 Monthly Hours of Sick Leave and SF-36 Pain Scores
(Health data taken from survey months: March 2001, April 2001, July 2001, December 2001, and May 2002.)

	Fixed effects	Random effects
Constant	7.08*	8.38**
	(3.35)	(3.78)
Female	—	0.40
		(0.64)
Age	—	–0.03
		(0.04)
Tenure	—	–0.00
		(0.04)
Disabled	—	1.40
		(0.91)
Education	—	–0.01
		(0.20)
Collector	1.87	0.85
	(3.68)	(0.57)
Level	0.22	–0.18
	(0.96)	(0.32)
SF-36 pain score	–0.04**	–0.03**
	(0.02)	(0.01)
Observations	855	855
Overall R^2	0.0165	0.0241

Standard errors in parentheses; * = significant at 10%; ** = significant at 5%.

Table 9 Percentage Increase in Production, Chair and Training Intervention

	Health Effects	Total Effects
A. Change in production per day per change in SF-36 pain score (Table 6, fixed effects)	$19.14	—
B. Change in pain score per intervention (Table 5, fixed effects)	6.23	—
C. Average total benefit per day (A × B)	$119.24	$ 353.11
D. Predicted average daily production, pre-intervention	$1,993.98	$1,993.98
E. Percentage increase in production (C/D)	6.0%	17.7%

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Endnotes

[1] While the analysis here focused on changes in monthly pain levels, Amick et al., forthcoming, analyzed the effect of these two interventions on the daily growth in pain scores. The pain scores used in both papers are distinct and come from different sets of questions administered during the study. The pain score used here is a monthly average, while the pain score used by Amick et al., forthcoming, is tabulated three times a day for five days a week during each of the survey months.

[2] A few support staff did participate in the study. While these individuals contributed to the analysis of health, they were excluded from the productivity analysis because there was no data on their production.

[3] Boden and Galizzi (1999) show that workers' post-injury wages are depressed relative to baseline after suffering a MSD that causes them to miss time from work. While this study is often cited as a source of productivity loss, on-the-job productivity losses due to chronic pain are almost never calculated.