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New Equipment to Lighten the Work Load of Construction Workers

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New Equipment to Lighten the Work Load of Construction Workers

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The objective of this study was to determine whether the 4 pieces of equipment for cutting moulding, cutting reinforcement rods, carrying carpet rolls, and fitting drain pipes can lighten the work load of construction work. The results indicate that the effect of using the new ergonomically designed equipment was positive. The cutter for reinforcement rods proved to be useful, bent back postures decreased by 11%. The carrying of carpet rolls became less loading on the lower and upper extremities. According to the men the work load was lower in fitting drain pipes, especially on the lower extremities and in the neck and shoulder region.

The conclusion was reached that work load can be decreased with well-planned equipment, but more attention should be given to personal work methods and habits.

ergonomics   construction equipment   work methods

1. INTRODUCTION

Construction work requires good functional capacity and the ability to control diverse work content. There is a certain freedom in the work, but otherwise the busy tempo is straining both mentally and physically. Physical demands are emphasized in particular in lifting, which drastically loads the

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musculoskeletal system (Eisenbach & Spannhake, 1983). Lifting and carrying are manual work for construction workers, and the loads often exceed the recommended limits (Koningsveld & van der Molen, 1997). According to Koningsveld and van der Molen (1997) the internationally accepted limit (30% of maximal oxygen consumption) for energetic load is exceeded by many construction workers. A study carried out in Sweden on construction workers found that repetitive loading resulted in faster development of discomfort or pain and that led to a need for longer pauses (Rose, 1992).

Construction work overloads the worker and gradually leads to high risks for musculoskeletal disorders (Heeg, Biefang, & Fliedner, 1989; Leino-Arjas, Liira, Mutanen, Malmivaara, & Matikainen, 1999). According to a study on construction work (Matikainen et al., 1999), musculoskeletal disorders are the greatest cause of decreasing work ability. Every fifth construction worker has experienced musculoskeletal disorders and symptoms, and disorders and symptoms increase with age. Physical capacity decreases with age, and therefore older workers clearly experience strain. Working on one's knees causes symptoms in the knees of, for example, carpet layers, but they also have back pain (Heeg et al., 1989). Unbalanced and loading work postures increase low-back pain (Homlström, 1992), but the assessment of the influence of the work postures used in construction work on these disorders is difficult because the exposure time is long. However a relationship between symptoms and ageing has been found for construction workers (Leino-Arjas et al., 1999; Matikainen et al., 1999). Concrete reinforcement workers show degenerative changes 10 years earlier than painters (Riihimäki, 1990). Musculoskeletal disorders are, indeed, the largest cause of early retirement among construction workers (LEL Työeläkekassa, 1995).

Equipment to lighten the work of construction workers has been developed, but its use is not common in Finland. According to one study (Heeg et al., 1989) the work load of construction work can be decreased by implementing the use of technical equipment and improving the work environment. According to Heeg et al. (1989) the ability of workers to profit from ergonomics in their work should be increased. Saloniemi (1995) noted in his study that the construction industry made very few changes that affected the strain of manual work from 1984 to 1990. Musculoskeletal overloading in manual materials handling remains if it is not prevented by ergonomic improvements. Smallwood (1997) has stated that many ergonomic problems can be prevented if construction equipment is planned. To promote health in construction work physically straining work postures and unbalanced work movements should be improved and ergonomic knowledge on work methods should be increased. Although the realization that the scope of work should be changed has spread over the last few years, work must still be done with old-fashioned methods (Landau & Wakula, 1997).

The aim of this study was to determine whether the use of four pieces of equipment developed to lighten work load decreases the strain of construction work during (a) the cutting of moulding, (b) the moving and cutting of concrete reinforcement rods, (c) the carrying of carpet rolls, and (d) the fitting of drain pipes. In addition, the use of equipment was evaluated to determine the need for additional improvement.

The effect of new equipment on muscular load has been reported by Sillanpää, Lappalainen, Kaukiainen, Viljanen, and Nyberg (1999).

2. PARTICIPANTS AND METHODS

2.1. Participants

Thirty-nine healthy, experienced construction workers took part in the study. For the cutting of moulding, the moving and cutting of reinforcement rods, and the carrying of carpet rolls 10 participants were used for each task. In the fitting of drain pipes 9 men were used. The mean age of the men was 39 years (range 23–54), their mean weight was 80 kg (range 65–106), and their mean height was 178 cm (range 167–187). The aerobic capacity of the men was measured with a bicycle ergometer and was found to correspond to that of the average Finnish male population (Heliövaara & Aromaa, 1980; Viljanen, Viitasalo, & Kujala, 1990).

2.2. Experimental Procedures

During the first three experiments (the cutting of moulding, the moving and cutting of reinforcement rods, and the fitting of drain pipes) the men alternated between the old and the new methods. In the first two every phase lasted 2 min, but in the drainpipe fitting the workers proceeded at their own tempo because of the layout of the construction site. When carpet rolls were moved, the workers not only alternated between the old and the new methods but also between being positioned in the front and back end of the roll. The workers were given the opportunity to practice each new procedure before the actual test.

The cutting of moulding and the carrying of carpet took place in storage spaces where the temperature was 22–24 °C. The handling of concrete reinforcement rods and drain pipes was done outdoors at temperatures of 1.8–4.0 and 21.0–25.8 °C. The work tasks were first carried out as usual on construction sites and then repeated with the use of the equipment prototypes.

When moulding was cut according to the old method, the worker squatted or worked on one or both knees (Figure 1). The cutter was on the

Figure 1. Cutting moulding with the old method.

Figure 2. Cutting moulding with the new method.

floor straight in front of the worker and the mouldings were on the right side of the cutter. The participant put the cut pieces of moulding (length 10 cm) on the floor on the left side of the cutter at a distance of 50 cm. The cutting height was 15 cm from the floor, and waste remained on the cutter surface and had to be removed by hand. When working with the new method (Figure 2), the worker was able to stand. The cutter was placed on an adjustable bench so that the cutting height was 57.5–66.5 cm (worker's own opinion of suitability). A bucket for the waste was positioned under the bench. The mouldings for cutting were on the right side, at the same height as the cutter.

The old method of moving and cutting concrete reinforcement rods was done at a height of 20 cm (Figure 3). The rods were on the ground in a pile on the right side of the worker, from which he pulled or carried them to the cutting device. After cutting the rods, he put them on the ground at his side. With the new method the worker cut the rods in a standing position (Figure 4). He took the rods from a storage rack supplied with rollers to lighten the pulling motion. The bench height was 70 cm, as was that of the cutter. The worker put the cut rods on his left side on a surface, which was at the same height as the bench.

Figure 3. Moving and cutting concrete reinforcement rods with the old method.

With the old method 2 men are needed to carry carpet rolls (Figure 5). They carried a carpet roll that weighed 70 kg, was 202.5 cm long, and 30 cm

Figure 4. Moving and cutting concrete reinforcement rods with the new method.

in diameter. The carpet was lifted from the floor and transported manually also up stairs. When working with the new method, the participants used devices: a metal bar supplied with rollers and handle (Figure 6). The metal bar was inserted into the holes in the ends of the roll. When the device was used, carrying was eliminated except on stairs, where the carpet roll had to be lifted

Figure 5. Carrying a carpet roll with the old method.

Figure 6. Carrying a carpet roll with the new method.

with the aid of the handle of the device. The grip was then at hip level. The man at the back walked forward with both the old and new methods. In one of the ten experiments with the old method the man in the front walked backwards, in the other experiments this man walked forwards. When working with the new method, 7 men walked forwards and 3 men backwards.

Figure 7. Fitting drain pipes with the old method.

When fitting drain pipes with the old method (Figure 7), the worker put the washer around the pipe on the ground, and lifting it by hand, fit the pipe into the pipe in front. The bent back posture and the need for a firm grip made the work difficult. In the new method (Figure 8), the worker applied the washer in the same way, but used a lifting strap with loops for the hands at both ends to help lift the pipe. The new method gave the worker control over the back posture during the handling of the pipes. With both methods another worker helped to join the pipe with the pipe in front of it.

Figure 8. Fitting drain pipes with the new method.

2.3. Measurement Methods

The Ovako Working Posture Analysis System (OWAS) was used to determine the work postures used in the tasks (Louhevaara & Suurnäkki, 1991). For this analysis the work of the participants were videotaped. The analysis was carried out at 5-s intervals, and, in addition, the cutting of reinforcement rods and the fitting of drain pipes was also analysed at 2-s intervals, so that a more exact evaluation could be made (Table 1).

Heart rate was measured during the work phases with a heart rate monitor (Polar Vantage, Polar Electro, Finland). To determine a worker’s cardiorespiratory capacity, a submaximal bicycle ergometer stress test

TABLE 1. Work Postures With the Old and New Methods, as Analysed With the Ovako Working Posture Analysis System

	Total Observations		Observations/Participant					
	Old Method	New Method	Old Method			New Method		
Type of Work	(Pieces)	(Pieces)	*M*	Q_1	Q_3	*M*	Q_1	Q_3
Cutting moulding (*n* = 10)	753	761	75	73	77	77	76	77
Moving and cutting concrete reinforcement rods (*n* = 10)	1628	1630	171	150	174	164	156	168
Carrying carpet roll (*n* = 10)								
Back position	237	238	11	10	11	12	12	13
Front position			10	9	12	12	10	12
Drain pipe fitting (*n* = 9)	439	452	43	33	49	50	41	52

Notes. *n*—number of workers, *M*—median, Q_1—lower quartile, Q_3—upper quartile.

(Louhevaara, Ilmarinen, & Oja, 1980) was carried out indoors for each participant at the end of the work performance. The result was estimated with a 3-point extrapolation method according to heart rate and work load, and it was adjusted to account for the participant's weight. In order to determine the work load the average heart rate during the work phases was compared with the maximal heart rate.

After the task was completed the participants were asked to rate (>0—*much lighter*; 0—*no difference*; <0—*much heavier*, scale 2— –2) the degree of benefit attained with the use of the new methods. In addition, they were requested to mark the strain of the neck and shoulders, low-back, and lower and upper extremities on a 100-mm visual analogue scale (VAS; Revill, Robinson, & Hogg, 1976) for the carpet roll carrying and the drain pipe fitting.

2.4. Statistical Methods

In order to assess the differences between the old and new methods the Whitney-Mann-Wilcoxon test and *t* test for dependent samples were used. The baseline has been expressed as the median and upper and lower quartiles. The results are presented as means and confidence intervals or as median and upper and lower quartiles.

3. RESULTS

3.1. Work Postures

In the cutting of moulding with the new method, there were fewer bent back postures than with the old method at the group level, even though some of the participants (3 out of 10) used bent back postures more often. Working with the new piece of equipment, the use of a raised arm position (upper extremity above shoulder level) was more common for some participants with the new method than with the old method, but the difference was not statistically significant.

With the old method, reinforcement rods were moved and cut at the worker's ankle level and the back was bent. In addition, pulling the steel rods from the bundle was difficult because they were entangled and the worker had to have his strength and use twisted and bent postures. With the aid of the new equipment the steal rods were on a bench at the same level as the cutter, and the roller on the bench made the pulling work easier. Bent postures decreased by 11% units (Table 2), and this value was statistically significant.

TABLE 2. Bent Back Postures With the Old and New Methods as Analysed With the Ovako Working Posture Analysis System

	Time Spent in Bent Back Postures (%)				
Type of work	**Old Method (*M*)**	**New Method (*M*)**	**Change**	**95%CI**	
Cutting moulding (n = 10)	95	92	–3	–2	7
Moving and cutting reinforcement rods (n = 10)	25	14	–11	7	13
Carrying carpet roll (n = 10)					
Back position	9	3	–6	–2	15
Front position	19	3	–16	1	35
Drain pipe fitting (n = 9)	80	83	3	–10	3

Notes. n—number of workers, M—mean, 95%CI—95% confidence interval.

Bent back postures decreased 16% units for the man in front when the new equipment was used to carry carpet rolls. In addition, the men in the back position during the carpet carrying and the men fitting drain pipes had fewer bent back postures, but the difference was not statistically significant.

TABLE 3. Heart Rate (Beats per Minute) of the Participants When Working With the Old and New Methods

	Heart Rate																
	Old Method					New Method					Change			
Work	***M***	**95%CI**			**% per Maximum**	***M***	**95%CI**			**% per Maximum**	**% Unit**	**95%CI**		
Cutting moulding (*n* = 10)	94	83	—	104	52	90	77	—	102	50	–4	–7	—	–1
Moving and cutting reinforcement rods (*n* = 10)	91	60	—	123	52	97	85	—	109	55	+6	–15	—	–2
Carrying carpet roll (*n* = 10)														
Back position	118	107	—	130	66	99	85	—	113	54	–19	–24	—	–14
Front position	119	108	—	131	66	101	88	—	114	55	–18	–24	—	–13
Drain pipe fitting (*n* = 9)	105	95	—	115	59	103	95	—	111	58	–2	–7	—	+3

Notes. *n*—number of workers, *M*—mean, 95%CI—95% confidence interval.

3.2. Heart Rate

The heart rate of the participants who moved and carried carpet rolls decreased by 20 beats a minute with the new method, but, during the cutting of moulding, the moving and cutting of reinforcement rods, and the fitting of drain pipes, the changes in heart rate were smaller (Table 3). The heart rate (percentage of maximal heart rate) decreased the most during the carrying of carpet rolls as a result of the new method.

3.3. Perceived Strain

During the carrying of carpet rolls perceived strain decreased the most in the lower ($p < .001$) and upper ($p < .05$) extremities (Table 4). In the fitting of drain pipes, perceived strain decreased the most in the lower extremities ($p < .05$) and in the neck and shoulder region ($p < .05$) when the new

TABLE 4. Perceived Strain of 10 Workers as Measured on a 100-mm Visual Analogue Scale (0—*no strain*, 100—*a lot of strain*) in Carrying a Carpet Roll With the Old and New Methods

	Old Method			New Method		
Region of Strain	***M***	**Q_1**	**Q_3**	***M***	**Q_1**	**Q_3**
Neck and shoulders	21	0	50	12	1	14
Low back	11	0	30	3	0	12
Lower extremities	75	47	86	20	13	23
Upper extremities	28	10	47	4	0	17

Notes. *M*—median, Q_1—lower quartile, Q_3—upper quartile.

TABLE 5. Perceived Strain of 9 Workers as Measured on a 100-mm Visual Analogue Scale (0—*no strain*, 100—*a lot of strain*) When Using the Old and New Methods of Fitting Drain Pipes

	Old Method			New Method		
Region of Strain	***M***	**Q_1**	**Q_3**	***M***	**Q_1**	**Q_3**
Neck and shoulders	44	25	58	11	6	24
Low back	46	22	63	16	8	36
Lower extremities	59	35	69	22	7	31
Upper extremities	25	7	58	21	10	30

Notes. *M*—median, Q_1—lower quartile, Q_3—upper quartile.

TABLE 6. Participants' Ratings of Degree Benefit of the New Method of Cutting Moulding ($n = 10$), Moving and Cutting Concrete Reinforcement Rods ($n = 10$), Carrying Carpet Rolls ($n = 10$), and Fitting Drain Pipes ($n = 9$) According to the Responses to the Questionnaire (>0—*much lighter*; 0—*no difference*; <0—*much heavier*, scale 2— –2)

Question	Cutting Moulding		Moving and Cutting Concrete Reinforcement Rods		Carrying Carpet Rolls		Fitting Drain Pipes	
	M	95%CI	*M*	95%CI	*M*	95%CI	*M*	95%CI
What difference occurred in the need for strength and in the work load?	0.6	1.1 — 0.1	1.7	2.0 — 1.3	2.0		1.8	2.1 — 1.4
What difference occurred in the work posture (back posture, etc.)?	1.3	2.1 — 0.6	1.7	2.0 — 1.3	1.7	2.0 — 1.4	1.9	2.1 — 1.6
What difference occurred in work convenience (fitting in hand, hand posture, etc.)?	0.4	0.9 — –0.9	1.3	1.8 — 1.0	1.6	2.0 — 1.2	1.6	2.0 — 1.2
What differed in the work tempo (fast, etc.)?	0.9	1.6 — 0.2	1.2	1.7 — 0.7	1.4	1.8 — 1.0	0.8	1.3 — 0.1

Notes. *M*—mean, 95%CI—95% confidence interval.

equipment was used (Tables 5). In the cutting of moulding and the moving and cutting of reinforcement rods, perceived strain was not enquired about.

3.4. Perceived Advantages of the New Equipment

As a rule, the participants reported that the new equipment lightened their work (Table 6). The participants reported that, for the cutting of moulding, the improvement in the work posture was the best feature of the new equipment, whereas the best features of moving and cutting reinforcement rods with the new method was the lighter pulling of the rods because of the rollers, better work height, and the possibility to measure the steel rods more accurately. In the carrying of carpet rolls less need for strength and less load on the back and lower extremities were the best characteristics. The participants assessed the construction of the equipment as simple and handy. The pipefitters preferred better work posture and the feasible use of the loop.

4. DISCUSSION

The test conditions were typical of normal construction work, and the participants were construction workers who did the required task as part of their job. The differences in the work methods were due to the different approaches to the work, for example, as in the carrying of carpet rolls. Variation in the work habits occurred however between the participants. The use of equipment in these tasks was new, and the participants would need to practice the new procedures longer. In the evaluation of the back load with the OWAS method, a 2- to 5-s work segment was analysed from a videotape. Nevertheless the OWAS method was not sufficient for evaluating the raised positions and joint angles of the upper extremities and the squatting positions of the lower extremities. The method does not include a classification of joint angles of the elbows, wrists, hips, knees, and ankles.

The responses of the workers who carried carpet rolls and fitted drain pipes confirmed our observation of work strain. The muscles of the lower extremities had to function strongly in both work tasks. The fitting of drain pipes also created much strain in the muscles of the upper extremities and the neck and shoulder region, and the participants reported that this strain was reduced when the new method was used.

Back posture was better with the old method in the cutting of moulding, but the need for strength in the upper extremities and control of the center of gravity in the trunk was greater. Furthermore, working in a squatted position or on the knees is troublesome and raises heart rate. According to our observations the participants who cut moulding had to be bent forward when working with the new method because the bench could not be adjusted to a high enough level. However, if the back had been straight, the demand for strength and the load on the joints of the upper extremities would have increased because the handle would have been too high. From the point of view of the wrist, the handle would have been located so that the participants would not have had to bend their wrists to the back or side. The effect of the new equipment on the moving and cutting of reinforcement rods was significant for the back posture and for the use of strength. The new method for fitting drain pipes would have provided for straighter postures if the lifting strap had been suitable for the participants' anthropometric measures.

In conclusion this study shows that work load can be decreased with the use of ergonomic equipment and work methods.

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