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NOTES

An Ergonomics Approach Model to Prevention of Occupational Musculoskeletal Injuries

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The objective of this study was to prevent occupational musculoskeletal injuries. Our workers stacked boxes of ceramics weighing 10–27 kg, making low back pain common in our enterprise. In all the stacking stations, recommended weight limits (RWL) were separately calculated using the revised National Institute for Occupational Health lifting equation. Since the boxes weighed significantly more than the RWL, we developed a new ergonomic design that completely changed the stacking process. The load put on the workers' waist vertebrae in the new and the old stacking methods was compared to evaluate the success of the new ergonomic design, using Newton's third law of motion. Thanks to the new ergonomic design, the load on the workers' vertebrae decreased by 80%. Due to its simple technology and its very low cost compared to robots, the new ergonomic design can be commonly used in enterprises with repeated and constraining stacking.

low back pain ergonomic design heavy lifting stacking musculosceletal injury organizational stress

1. INTRODUCTION

An individual's capacity and motivation to work interacts with the character of the work and the individual's environmental conditions. Our personal success at the end of the day is the product of those two factors. Throughout the course of history, modes of labor have changed drastically as a result of changes in environmental conditions and changes in the relationship between the means of production and individual needs. However, because the laws of physics remain constant, the pressures put on our bodies have remained largely the same.

Physiological problems, such as muscle aches, lack of energy, increase in heart rate, and difficulties in respiration, limit the amount of work done and the amount of time spent working. Manual workers may be exposed to more physical pressure than they can bear because of their personal motivations for working (for a sense of belonging, as a form of self-expression, for financial security, etc.) or the harsh conditions sometimes found in industrial production. When the workload increases despite workers' physiological problems, those workers may have to choose between their health and their jobs. The choice is subject to a great number of variables: employer sensibility, the stringency of laws and regulations, employee knowledge of health and safety as well as the ability to demand equal treatment.

Musculoskeletal disorders are difficult to treat and recover from, thus postdisorder problems and complications are common. Laborers experiencing these difficulties, even when they are treated, may

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not perform as effectively as they used to and may have to face the risk of losing material assets and psychological well-being they would have liked to acquire by working.

A worker's loss of health due to occupational injuries is similar to an employer's loss of capital due to business problems. In both situations, work cannot be done as before and tragic social consequences are likely to emerge. Therefore, good health is absolutely critical for a laborer. Instead of palliative regulations, studies related to workers' health problems should seek to create regulations that are preventive in nature and aim at ensuring sustainability. At the same time, the social dimensions, which are not always properly recognized, should not be ignored.

2. METHOD

The revised National Institute for Occupational Health (NIOSH) lifting equation method was used to evaluate repetitive and forcible heavy lifting operations in departments where stacking was part of the daily regimen [1].

Measurements for the revised NIOSH lifting equation method were taken at all the stacking stations. Because there were a many work stations and boxes, the smallest horizontal location where a box was loaded on a pallet was determined to perform a single task assessment for each storey or level. Each storey's lifting index (LI) in this setup was calculated individually as the final point of the task and the highest values were assumed to represent the whole task. Assuming that workers, stacking boxes between the pallet and the conveyor belt, were at the very center of the sagittal platform of the lifting and the final sections, the asymmetric angle was measured at 60° and the horizontal distance at 0.5 m for both points (Figure 1). It was supposed that workers worked 7.5 h a day and stacked 5.5 h of that time, due to 2-h task rotations.

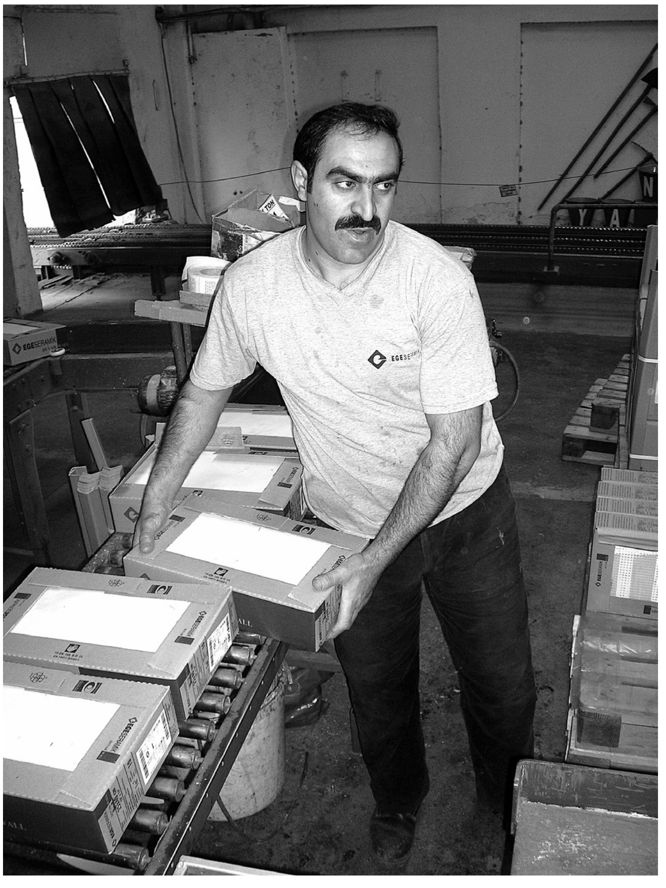

Figure 1. The transfer of the boxes from the belt conveyor onto the pallet using manual force.

The LI rate was larger than the one in all our stacking stations (Table 1). Musculoskeletal injury risk increases as this rate increases. The health records of the workplace health unit showed that the LI rates correlated with the prevalence of low back pain in the first 8 months of 2006 (Figure 2). General and renewed design proposals offered by the NIOSH recommended weight limit (RWL) equation for situations when LI was bigger than one were examined; however, when the requirements of our work and our workplace were taken into account, it was not considered feasible to reduce the LI to one or lower rates.

TABLE 1. Lifting Index per Hall

Hall	Lifting Index
1	2.35
2	3.72
3	2.61
4	2.27
5	2.90
6	1.12
7	2.57
8	4.14
9	5.16
10	2.39

In this situation, the option of using robots in an automated stacking system could be considered. Nevertheless, robots were cost prohibitive and our stacking sections did not have the space in which such systems could be installed. We also looked unfavorably on this option because automation would involve the unattractive prospect of layoffs.

After taking into consideration the nature of the work, our workers, and our enterprise, we developed a new method, which would ease the strain from stacking operations through the use of ergonomic designs. The following criteria were considered: repetitive and forcible actions should be minimized, workers should not lose their jobs, costs should be reasonable, the speed and the quality of stacking should not be hindered, workers should be included in the development of the project to process their input and allow them to more easily internalize the project, and decrease in risk should be measurable via new regulations.

We looked for sources of mechanical force which did not include high amortization and energy costs. After some brain-storming, we considered a well-known source of force: gravity. The stress of constant lifting causes harm to the

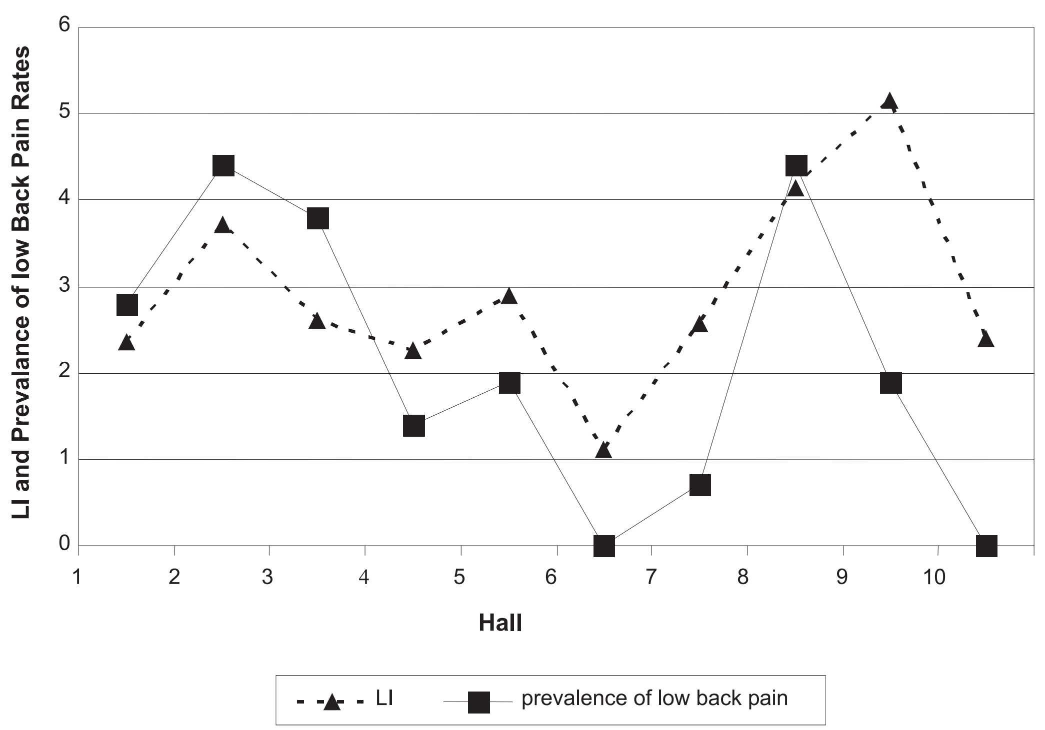

Figure 2. A comparison of the lifting index (LI) and low back pain prevalence per hall.

musculoskeletal system but while gravity is an unavoidable reality, there are ways to ameliorate its harmful effects.

In the new design we cut the conveyor belt to create a transport bridge and an additional mini conveyor belt was placed on the pallet under this bridge. By providing appropriate inclines to the conveyor belts, we created a mechanism in which boxes could move along without having to be lifted. The proximal edge of the severed part was given more incline; thus a box moving in a horizontal position was ensured verticality by falling under its own weight. As boxes moved along on the pallet they were automatically stacked without needing to be lifted or carried (Figure 3). To ensure that boxes slid evenly on every level of the pallet, we installed a hydraulic transport platform under the pallet. To prevent injuries incurred from boxes falling on workers' feet, we also placed mobile barriers on the edges of the pallet and the mini conveyor belt. To prevent possible damage to the boxes, we put a plastic hose over the rolls of the mini conveyors belt. When the first stacking level on the pallet was completed, we also lowered the hydraulic platform a little for the second level (Figure 4). When the pallet filled up, the bridge closed, bringing the flow of the boxes to the level of the next pallet and allowing the stacking operation to be performed on the next pallet.

3. COMPARISON

3.1. Action and Reaction Forces

We measured the opposing forces which affect the waist vertebrae during the stacking of a single box. The distance between the axis of the body

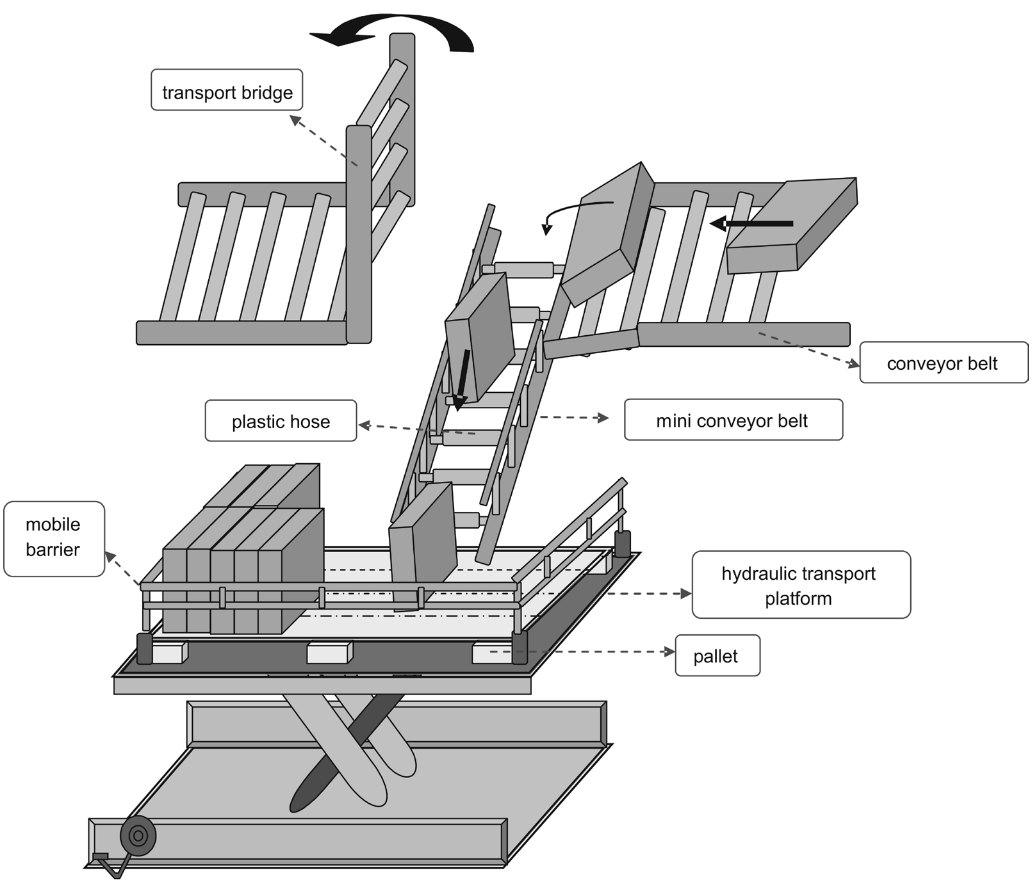

Figure 3. The stacking of the first storey of the pallet in the new ergonomic design.

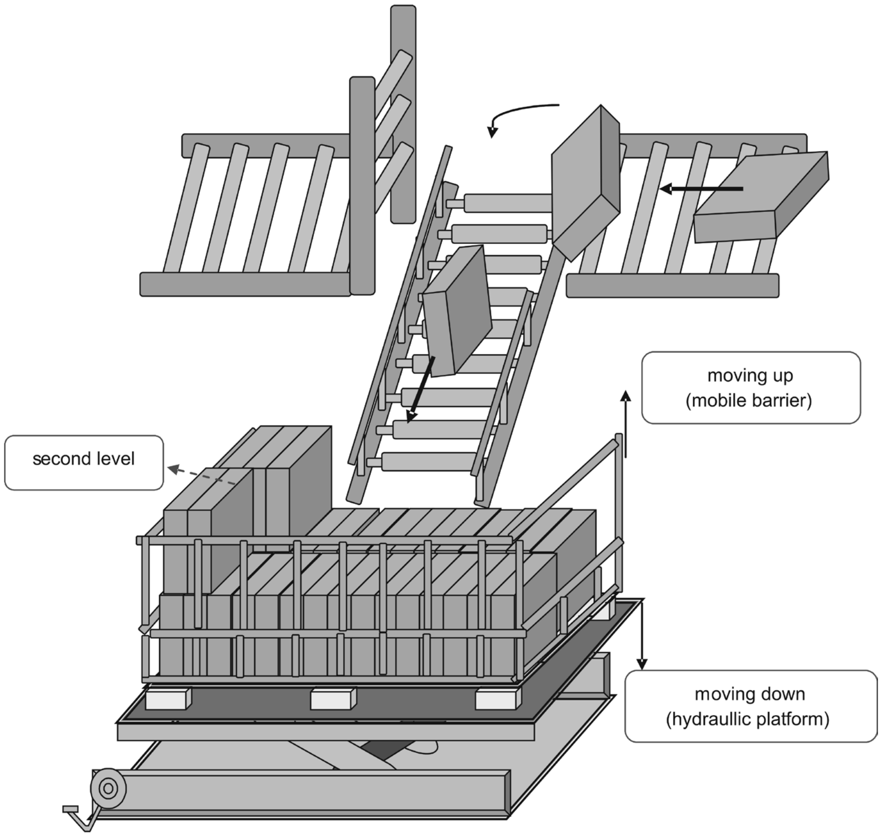

Figure 4. The stacking of the second storey of the pallet in the new ergonomic design.

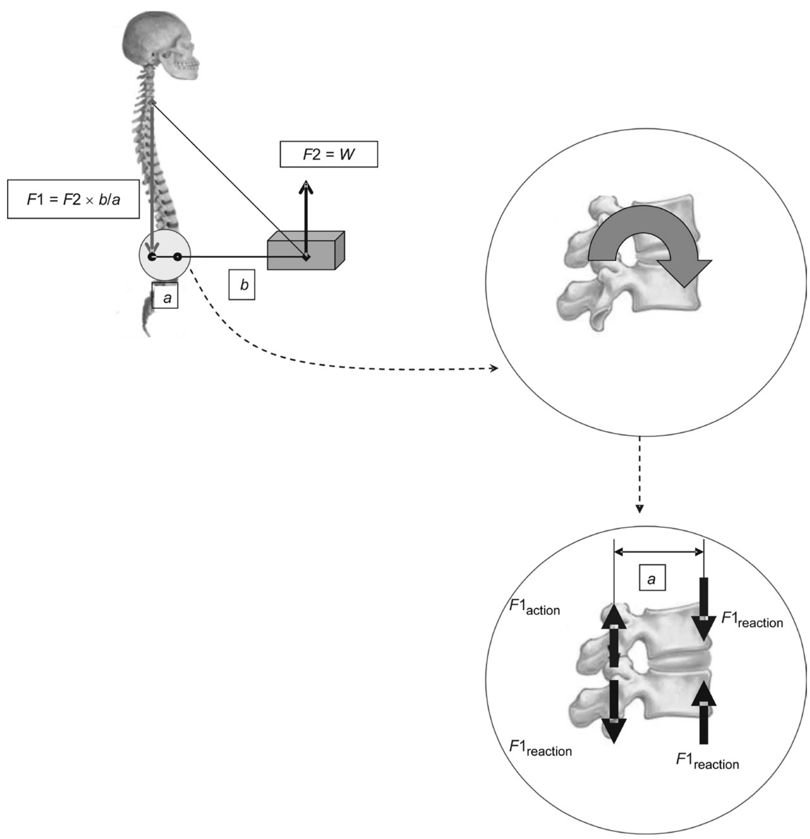

Figure 5. Forces exerted on waist vertebrae during lifting. *Notes*. *F*2, W—weight of the box in the pilot station, *F*1—force exerted on the vertebrae in the old mechanism, *b*—distance between the axis of the body and the load, *a*—horizontal weight of the vertebrae.

and the load was accepted as 0.5 m (*b*), and the horizontal weight of the vertebrae was accepted as 0.05 m (*a*). The weight of the box in the pilot station (*W*) was 12.2 kg. $F1 = (F2 = W) \times b/a =$ 122 N, where *F*1—force exerted on the vertebrae in the old mechanism (Figure 5).

In the new system, boxes were pushed instead of lifted; therefore, we needed to calculate the frictional coefficient between the boxes. Two boxes were placed one on top of the other and set on an incline. When the box above began to move, the angle of the incline was calculated at 16° through a set-square. The tangent of this angle was accepted as the frictional coefficient (μ) (tan 16 = 0.28) $F3 = W \times \mu = 3.4$ N, where *F*3—force necessary to push a box into the new mechanism.

The effect of the necessary force on the body to move the box of ceramics in its horizontal platform is represented by *F*3, the vertical effect of this force on the vertebrae by *F*4. The distance between the shoulders and the waist was accepted as 0.35 m (*c*). $F4 = F3 \times c/a = 23.8$ N, where *F*4—force exerted on the vertebrae in the new mechanism (Figure 6).

Consequently, with this new arrangement, the force exerted on the waist vertebrae decreased by ~80%. Because of these new implementations, grabbing, heavy lifting, 60° twists, and leaning towards the furthest part of the pallet were all eliminated. Workers now only had to push and slide boxes to arrange them (Figure 7).

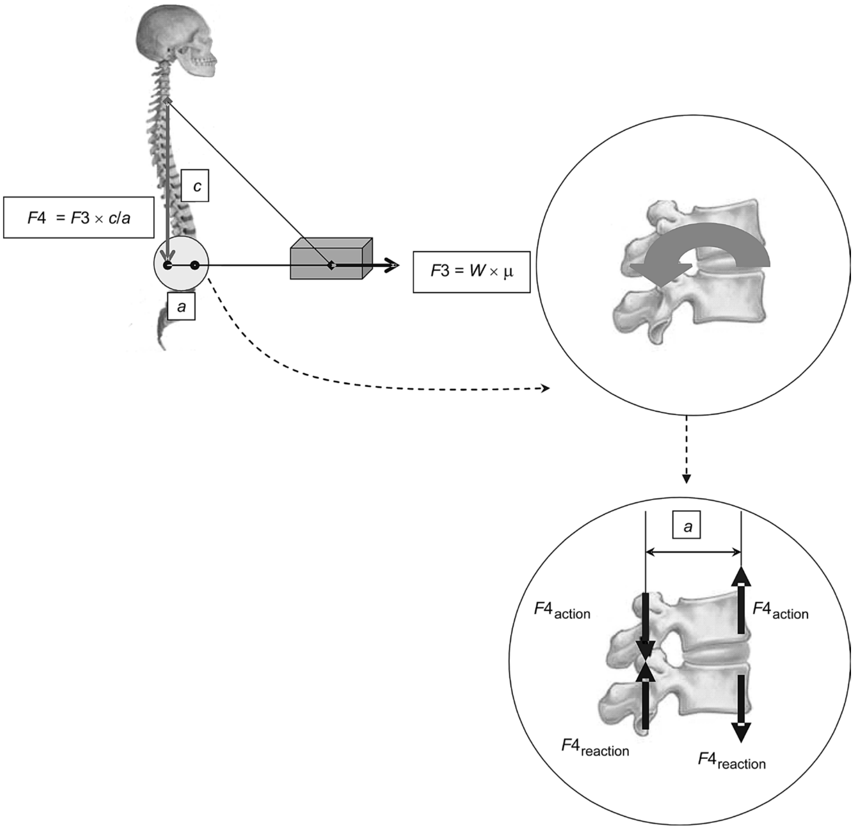

Figure 6. Forces exerted on waist vertebrae during pushing. *Notes*. *c*—distance between the shoulders and the waist, *F*4—force exerted on the vertebrae in the new mechanism, *F*3—force necessary to push a box into the new mechanism, *a*—horizontal weight of the vertebrae, *W*—weight of the box in the pilot station, μ—frictional coefficient.

Figure 7. The stacking by pushing boxes onto a pallet.

3.2. Heart Rate Increase

We need energy to gain the necessary strength to carry weight. It is possible to find information on these requirements by measuring various functional changes that occur during the production and exertion of energy, such as the level of oxygen consumption, changes in the heart rate, and other factors [2].

In our study, we used 5 workers from the first hall packing unit as our pilot group and evaluated them individually. We took pulse measurements during their break time. After their resting pulse had been measured, the subjects were asked to perform a controlled task. When the increase in their heart rate was compared in both methods, we observed an increase of an average of 20 points for the old mechanism, whereas only a 6-point, on average, increase with the new mechanism. Furthermore, in comparing the workers' heart rate using the new setup versus the old one, we also discovered that fatigue decreased by an average of 70% (Table 2). We, therefore, established that less energy was consumed in the new mechanism and that the workers, therefore, grew less tired. Since the envisaged changes to the conveyor belts in the new methods had not yet been made, the mechanism in the first prototype of the project was used (Figure 8).

TABLE 2. Comparisons of Heart Rate (beats/min)

	Previous Procedure			New Procedure		
Worker	Resting State	Continuous Labor	Difference	Resting State	Continuous Labor	Difference
1	78	108	30	78	84	6
2	81	104	23	80	88	8
3	76	104	28	76	88	12
4	92	110	18	90	92	2

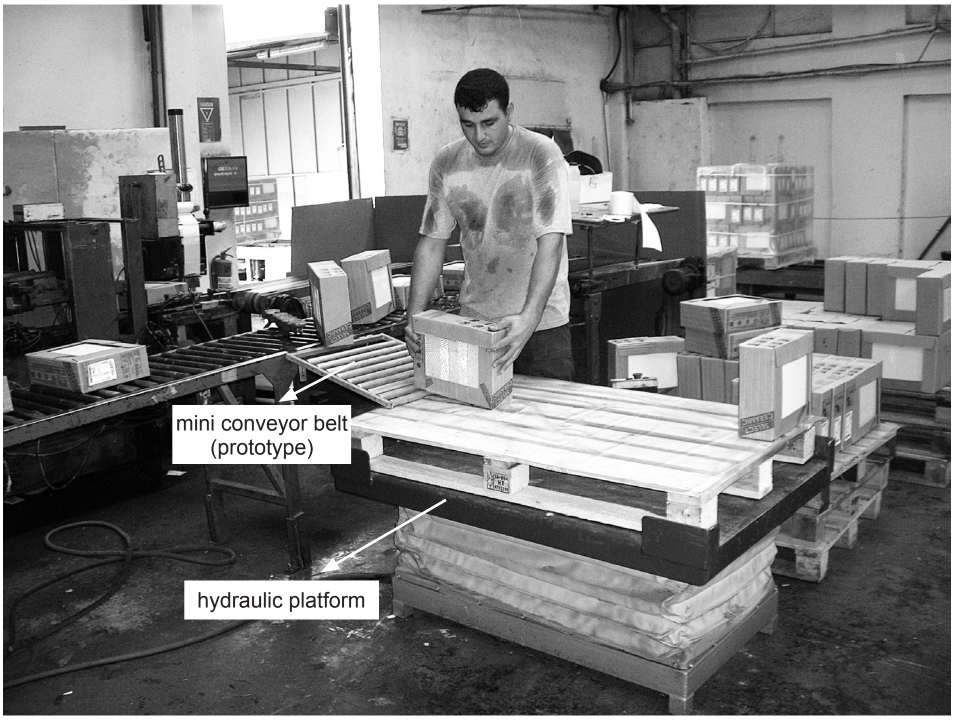

Figure 8. The prototype of the new ergonomic design.

3.3. Employment Injury Risks

Twenty employment injuries occurred in our stacking departments in 2006. Seven of those were the result of boxes falling on individuals' feet, five were due to sudden back pain, five were the result of a combination of tripping and head injuries from crossing under or over the conveyor. However, after barriers were added to the sides of conveyor bands, boxes could no longer fall from the conveyer belt. Also, we no longer expected sudden waist aches since the boxes were no longer be lifted or carried. With the addition of bridges over the conveyor belt that provided safe crossing points for the workers, the total rate of improvement in employment injury risks came to 85%.

3.4. Breaks

Workers carried out additional tasks related to box stacking, such as bringing empty pallets, placing cartons of boxes in the packing machine, stretching plastic over the pallet. In the old system, the inefficiency of the system created bottlenecks on the conveyer belt and led to peaks of activity and valleys of inactivity or rest. Under the old system, an average of 110 s of nonstop work would be followed by 202 s of continuous rest.

In the new design, as boxes were stacked only by pushing, about 20 s were saved per one stacking storey. Moreover, drawing the nylon cluster closer to the stacking field, using automatic encirclement machines instead of manual ones, thereby enlarging the storage capacity of cartons twofold, halved the necessary time to 15 s. Since 35 s were saved during each stacking storey, more frequent breaks could be given and workers grew less tired. As pointed out in a bicycle experiment conducted by Lehmann, Karrasch and Müller, carrying out a task in short intervals and in segments made it possible to have frequent breaks and, as a consequence, to grow less tired (as cited in Babalik [2]).

4. IMPROVEMENTS

4.1. Work Order and Official Breaks

In the old system, the break system was implemented by alternating a 3-h, nonstop stacking period with a one-hour, nonstop quality control period. Our study showed that mental fatigue was compounded by physical fatigue during the quality control operation. It was not possible to rest as physical stress, such as noise and thermal discomfort, were sometimes extreme. It was agreed that 3-h heavy stacking and one-hour quality control periods were not appropriate and that the break system did not serve its purpose. We, therefore, concluded that more short breaks would be more beneficial than fewer longer breaks.

In the new arrangement, two workers working in the ovens were included in the work rotation. In this way, stacking could be performed by 4 workers. Moreover, it was not necessary for the workers to do secondary tasks during their break. Therefore, they could have some mental and physical rest. In addition to decreasing difficulties encountered at the stacking stations, the rotation system decreased the work load and fatigue per worker. Thanks to rotation, monotony, another stress factor, was also alleviated.

4.2. Lighting

Lighting of a minimum of 200 lx was needed to stick neatly labels on boxes and subsequently boxes on pallets, and also for occasional interventions on digital devices. Table 3 lists lighting measurements taken from all stacking departments.

4.2.1. Light intensity and reflection degree

To attain target lighting levels, instead of providing more powerful lighting devices, light sources were lowered. Some transparent coverings which enabled us to benefit from the daylight from the roof were renewed, too.

Lighting devices and reflection-system-based walls were cleaned up and walls were painted white to take advantage of light reflection. We also covered the floor with white and luminous ceramics where appropriate. To perceive objects clearly, color contrasts between the boxes of ceramics, the conveyor belt and the hydraulic platform were adjusted. As it was not possible to change the color of the boxes, the conveyor belts and the hydraulic platform were painted dark. Since this area of the factory was a place of heavy, manual labor, we chose blue as a cooling and calming color. In this way, light brown and dark yellow boxes and pallets were now easier to see.

4.2.2. Vision acuity and depth

Numbers (1, 2, etc.), which signify the quality on the box labels, were doubled in size. They were also made thicker to make them easier to see.

4.2.3. Eye examinations

All workers from the stacking department had eye examinations carried out by the workplace health unit. Those who did not pass the exam were sent to hospitals to get glasses or new prescriptions.

The improvements listed in section 4.2. helped reduce the tiring effect caused by poor lighting and perception problems. The improvements also decreased the risk of accidents that would be caused by faster box stacking on proper pallets.

TABLE 3. Illumination Measurements (lx)

Hall	Measured Day Value	Measured Night Value	Day Evaluation	Night Evaluation
1	260.4	25.6	fit	unfit
2	426.5	473.7	fit	fit
3	233.7	20.5	fit	unfit
4	120.6	5.7	unfit	unfit
5	230.4	25.1	fit	unfit
6	60.9	93.9	unfit	unfit
7	70.4	101.5	unfit	unfit
8	108.6	25.2	unfit	unfit
9	13.7	250.9	unfit	fit
10	30.5	20.2	unfit	unfit

Notes. Optimum value >200 lx.

4.3. Noise

Table 4 lists noise measurements in all stacking departments. To reduce noise, its sources were located with noise detection devices, and emission and diffusion of noise were reduced. Workers used earplugs. It was observed that the sound of small pneumatic pistons which push ceramics into appropriate canals in the packing machines and the sounds caused by falling ceramics onto Teflon® felts generated considerable noise. Moreover, fan motors that use pressurized water to clean up ceramics on the belts also caused substantial noise.

We, therefore, experimented with rubber materials put over pistons to soften the hits. Their intensity was also diminished by reducing the amount of air pressure on the pneumatic pistons in a way that would not prevent its proper functioning. Secondly, the Teflon® felts on which the ceramics fell had not been changed for a long time and had, therefore, hardened. This increased the noise level considerably. Rubber and felt material were replaced with new ones, thus reducing noise emission. As constant production, corrosion and attrition are inevitable, longer-term solutions were also explored.

Since fan motor noise could not be prevented, we sought a different method to serve the same end. We found that a tray brush model could be used instead; it uses circular brush strokes to clean the ceramics and creates substantially less noise. To regulate the noise level, noise had to be measured again.

4.4. Thermal Comfort

Measurements carried out in December 2006 revealed that packing units in general conformed to thermal comfort conditions. However, due to 1 200 °C ovens in our enterprise and İzmir's humid climate, measurements would also have to be taken in the summer to get a better idea of the average temperatures during this hotter period of the year (Table 5).

TABLE 4. Noise Measurements (dB)

Hall	L_{eq}	L_{max}	L_{min}	Limit Value	Result
1	81.65	86.00	80.42	80	unfit
2	78.90	85.20	75.30	80	fit
3	78.90	85.20	75.30	80	fit
4	82.80	89.70	79.60	80	unfit
5	83.20	99.40	81.50	80	unfit
6	78.90	87.20	70.90	80	fit
7	81.10	91.20	77.70	80	unfit
8	85.60	91.20	75.10	80	unfit
9	82.04	86.74	79.28	80	unfit
10	87.80	98.10	83.50	80	unfit

Notes. L_{max}—maximum sound pressure level, L_{min}—minimum sound pressure level, L_{eq}—average sound pressure level between L_{max} and L_{min} in a defined time period.

TABLE 5. Thermal Comfort Measurements

Hall	Temperature (°C)	Relative Humidity (%)	Air Flow (m/s)
1	21.7	34.7	0.21
2	26.7	23.9	0.17
3	23.8	28.1	0.74
4	22.2	33.0	0.21
5	25.5	26.5	0.22
6	18.2	67.3	0.27
7	21.5	61.1	0.23
8	23.9	55.3	0.29
9	25.1	50.2	0.24
10	23.4	59.5	0.20

4.5. Nutrition

4.5.1. Determination of calorie needs

We first set out to calculate the number of calories workers in the stacking department needed for an average day of work. They were assumed to perform the same work as construction workers, thus it was agreed that a male worker of 65 kg used 6 Kcal/min during stacking operations. It was determined that a worker from the stacking department would use 2 880 Kcal during his 8-h workday, 520 Kcal during 8 h of sleep, 1 000 Kcal during out-of-work physical activities; therefore, he would need a total of 4 556 Kcal/day of energy (specific dynamic effect of nutrients: 156 Kcal). As 50% of the daily energy needs is recommended to be supplied at lunch, lunch menus in the workplace should be ~2 200–2 300 Kcal [3]. However, the average number of calories provided through workplace-provided meals during the past year was calculated to be only 1 472 Kcal.

4.5.2. Regulations on nutrition

Laborers lose more nitrogen through sweating and they have more muscle mass; therefore, in addition to merely increasing the number of calories (by an average of 400 Kcal), more proteins were put on the menu. Moreover, ayran, lemonade, tea, biscuits, etc., were served during break times. To increase psychological satiety, food was served on porcelain plates, table covers were changed, and olive oil, lemon juice, vinegar and spices were placed on the tables. Beautiful plants and paintings became part of the refectory. In addition, air conditioning was provided [3].

4.6. Organizational Stress

To assess psychosocial problems, rather than physical ones only, and to learn about workers' exposure to occupational stress, an organizational stress survey was conducted among 30 randomly selected workers from the stacking departments [4]. It turned out that even though workers generally liked their work and thought that it mattered, 50% of them did not expect to be doing the same job in the next 5 years. Also, 62% felt exhausted. The psychosocial stress factor seemed strong in stacking workers and indicated possible musculoskeletal disorders [5]. Results were shared with senior managers to define measures to be taken and the method to be employed; meanwhile, confidentiality was ensured. It was pointed out that workers did not merely constitute a group of people who were brought together for a job but that workplaces were social units, and that industrial psychology was a branch of science whose aim was to offer solutions to problems arising from the industrial environment [6]. Among these problems were listed personnel's recruitment and training, efficiency increases through the improvement of working conditions, prevention of occupational accidents and job satisfaction. Thus, it would be beneficial to employ an industrial psychologist in the workplace health unit. With the support of senior managers who attached great significance to the issue, the said recruitment was achieved.

5. DISCUSSION

Risk analyses related to musculoskeletal injuries are generally restricted to the evaluation of the physical properties of the work done in the workplace. However, life goes on 24 h/day and workers can perform chores that involve heavy lifting and carrying of, e.g., coal bags, shopping bags, etc., for their personal needs, too. For example, ~20% of our workers live in villages, on traditional, family-style farms. Therefore, additional work after the shifts are over is a normal part of their way of living. If workers who perform heavy lifting and carrying sleep in a bed of insufficient orthopedic quality, sufficient muscle rest will not be provided since the blood circulation will not be adequate. If strained spinal muscles do not rest properly, workers will have a higher likelihood of injury during their shift the next day.

If ergonomic arrangements are restricted to engineering applications at the workplace, workers no longer become the subject of our study but appear as mere biomechanical parts. This kind of approach would inappropriately diverge from the objective that labor should be adapted to the worker and not vice versa. Instead, factors like age, gender, anthropometric data, health histories, nonwork lives, exposure to organizational stress, satisfaction with work, rates of extra-shifts, vacations, etc., should all be considered in risk analyses. If those factors are not taken into account, we will expect unwanted surprises in health unit statistics.

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