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Objectives This field study analyzed work-related causes of musculoskeletal disorders to investigate the structure of physical workload in different occupations in the construction industry and rank different tasks with respect to the load on the lumber spine.

Methods An observation instrument (Arbeitswissenschaftliches Erhebungsverfahren für Bauarbeiten) and a specially devised data retrieval system (Allgemeines Datenerfassungs- und Analysesystem für Bauarbeit) provided material for a large database which allowed a differentiated analysis of load exposures. The study was comprised of data from 340 construction workers (bricklayers, scaffolders, carpenters, plumbers, and painters). On the basis of a regular daily worktime of 8 hours, specific statistical aspects were studied concerning manual materials handling, biomechanical pressure on lumbar disc L5/S1, and posture constraints during kneeling, squatting, bending and overhead positions.

Results The scaffolders (13.7% of the regular daily worktime), bricklayers using bricks requiring two hands (7.1%), and carpenters (6.7%) handled weights of >10 kg. With respect to lumbar disc L5/S1, the scaffolders and bricklayers often showed pressures in excess of 3.4 kN. Bricklaying required bent postures for 20.7–35.6% of the daily worktime. The painters (23.8%), plumbers (16.7%), and carpenters (7.2%) often worked in kneeling postures. The painters often used overhead positions (18.3%). The bricklayers and scaffolders had high frequencies of materials handling. The recovery time for this repetitive work was longer than threefold the load time.

Conclusions This study showed that it is possible to rank different construction tasks with respect to load exposure. In addition it was shown that preventive measures such as improved ergonomic design, organizational structure, training, and medical health care are needed.

Key terms construction workers; musculoskeletal disorders; field study; lumbar spine pressure; postures constraints; repetitive manual materials handling.

Depending on the type of building and the organizational structure of the construction site, different elements of work result in different load effects. Therefore, criteria are required for assessing workloads during the performance of different work sequences. However, in the construction industry, the structures of physical work stress involved different elements and aspects of strain (ie, heavy loads have to be manipulated in a wide range of frequencies, particular tasks lead to strenuous body postures, the time structure of strain and recovery with respect to the handling of different weights has to be considered, and repetitive manual materials handing results in a higher risk for the hand–arm system) (1, 2).

Several of these factors occur simultaneously and may cause complaints, medical abnormalities, sick leave, and musculoskeletal disorders. Therefore, recommendations have been developed to evaluate health risks (3–5), and preventive measures have to be taken against injuries, for example, as stated in German legislation on occupational diseases.

Strategies for preventing musculoskeletal disorders must be taken into consideration, along with a large variety of factors, such as the weights handled, the frequencies of action, the time structure of strain and recovery, and body posture. No information has been systematically collected about workloads, load from postural stress, and repetitive hand–arm work in the construction industry. Initial information has been obtained, however, from questionnaires regarding work conditions and from workers suffering from pain under stress (6–8), but this information is not sufficient to reveal the actual risks resulting from physical workloads. The initial idea of compiling a structured database on construction work developed simultaneously with the use of different strategies at different locations (7, 9–11).

The analysis of work-related causes of musculoskeletal disorders was the goal of this field study, which was carried out over a period of more than 5 years. A further objective was to investigate the structure of the

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physical workload of different occupations in the construction industry. [See the final reports of Fleischer et al (10–12).] Another goal was to rank different tasks of construction workers with respect to the load on the lumbar spine. Such a ranking would enable clear preventive measures to be concentrated on. Some of the major results from this study are reported in this paper.

Methods

An observation instrument called Arbeitswissenschaftliches Erhebungsverfahren für Bauarbeiten (AEB) and an analysis program called Allgemeines Datenerfassungs- und Analysesystem für Bauarbeit (ADAB) were specially developed by Fleischer and his co-workers for this study (11, 13). AEB is an electronically supported method of observation for the representation of elements of physical load. With the help of the specially developed analysis program ADAB, important components of physical load can be determined. For this purpose, construction work was categorized into distinct elements on the basis of preliminary investigations (evaluation of videos, photos, observations, questioning) covering (i) characteristics of the activity (activities and objects of work in the examined trade and workplaces), (ii) characteristics of body posture [workheight of the hands in respect to body position (lower floor, floor-, knee-, hip-, chest-, and shoulder-height and overhead)]; leg position (standing, squatting, kneeling, sitting), twists of the trunk and sideways inclination, and restrictions and confinements of the work area, (iii) characteristics of the load (weight, size and shape), and (iv) current time (internal computer timer).

When using the method, an observer records all relevant characteristics of load on a digital display as work is being carried out. Usually, different characteristics can be applicable at the same time (up to 7) for the description of a work situation. Because the input possibilities of a single person are limited, the repetitive characteristics of the work sequence are continually updated until the situation changes. Because the entries are made on a digital display of simple depictive symbols for the individual categories (figure 1), the observer is in a position to perform a rapid input without loss of concentration and decide on the correctness of the results at the time of the data entry. A video camera was not used for observation because building workers are very mobile during their work. Over the duration of the project, several different observers were involved in the investigation. In order to assure the quality of their data acquisition, we made internal comparative checks of the entries from several observers, as well as orienting work samples in order to confirm the plausibility of the data from the bricklayers. These backups confirmed the inter- and intraindividual reproducibility of the data acquisition from the different observers. Additional details can be found in the research report (11).

In all, the work of 247 construction workers was analyzed. The observation results provided a large database for further statistical analysis of the sequences, actions, and resulting workloads. The jobs and workers to be examined were selected before the project commenced. Most of the observed workers came from the region around Hamburg—with two-hand bricklayers being selected from western regions of Germany.

In order to set up a ranking of the construction tasks according to workload, we chose the following five different professional groups (table 1): (i) two-hand bricklayers [Br-th, N=31], and one-hand bricklayers in contract work [Br-ac, N=32], building multiple-family dwellings [Br-mf, N=30] or building single-family houses [Br-of, N=30], (ii) scaffolders assembling or disassembling scaffolds [Scaf, N=30], (iii) carpenters building roof trusses, formwork or scantlings, gathering up roof framing and carrying out roof repair works [Carp, N=33]; (iv) plumbers installing water pipes and fixtures [Plum, N=31]; and (v) painters painting houses (interior painting work, including work with the roller or spatula and wall-papering) [Pain, N=30].

All of the participants were healthy and fit for work and in an average age range. Our observations had no negative effect on their work performance.

Each day of observation covered at least 4 workhours, 2 hours before and after lunchtime. The data obtained were normalized with respect to the regular daily worktime of 8 hours (shift time).

Thus data were obtained on all actions on one observation day; the data covered the frequency and duration of each partial activity and type of load and were cumulated to result in a mean load.

The database provided the following data: (i) the distribution and averages of the weights handled and (ii) biomechanical pressure on lumbar disc L5/S1, calculated on the basis of the biomechanical model [the biomechanical computation took place with the data of the loads and body postures in accordance with the two-dimensional curves of the biomechanical model “Der Dortmunder” of Jäger et al (12), taking into consideration movement dynamics], (iii) working at a height between the hip and knees was regarded as a bent posture in the range of 30 to 60 degrees and working at a height between the knees and floor was estimated to be in a range of 60 to 90 degrees, (iv) the frequency and period of materials handling were analyzed in terms of load–recovery time in conjunction with the weights manipulated [load–recovery time means the relation of recovery times between two loads divided by the length of the load period].

Figure 1. An AEB display of the digital board occupied with depictive symbols of the load and work categories.

Table 1. Characteristics of the workers in the different professional groups.

Group	N=247	Age (years)		Height (cm)		Weight (kg)		Registered time (h:min:s)
		Mean	SD	Mean	SD	Mean	SD	
Bricklayers								
Using two hands	31	37.8	13.25	180.2	4.81	83.0	6.31	144:13
Using one hand in contract work	32	36.6	11.22	181.4	5.66	83.2	8.72	112:30
Making houses for multiple families	30	36.9	11.31	178.7	4.09	83.1	9.30	98:59
Building single-family houses	30	38.8	11.67	180.5	5.24	87.2	9.29	94:06
Scaffolders	30	35.6	7.73	181.1	6.65	87.5	14.65	99:09
Carpenters	33	34.9	9.88	182.2	5.63	87.1	10.22	131:43
Plumbers	31	38.8	9.04	177.1	5.99	82.3	11.81	113:58
Painters	30	38.9	11.94	176.9	6.21	80.2	8.77	103:13

Results

This study analyzed five professional groups with respect to weights and the frequency of the materials handled, body posture, biomechanical pressure on lumbar disc L5/S1, and the load–recovery time ratio.

The loads from materials and tools handled differed greatly among the different professional groups (figure 2). Weights of >10 kg were handled by scaffolders during 14.9% of their shift, by two-hand bricklayers during 7.1% of their shift, and by carpenters during 6.7% of their shift. Some of them had to manipulate even weights of >25 kg, and, in extreme cases, scaffolders even had to handle >50 kg (table 2). Lower weights ranging from 5 to 10 kg were found for bricklayers doing piecework (19.3% of shift) and bricklayers building

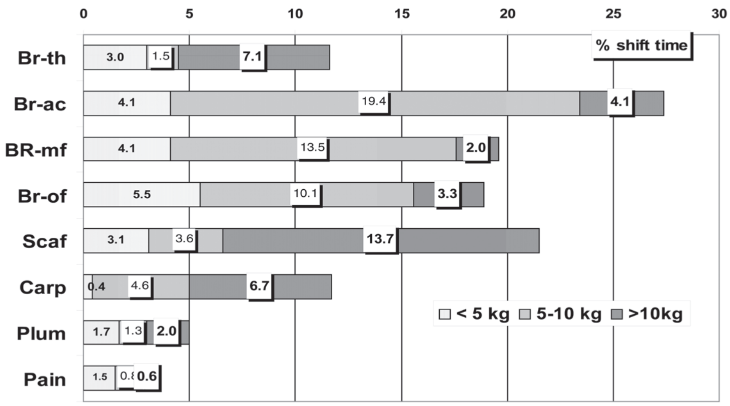

Figure 2. Load stress from handling materials and tools for different types of construction work (Br-th = two-hand bricklayer, Br-ac = one-hand bricklayer, Br-mf = bricklayers building multiple-family dwellings, Br-of = bricklayers building single-family houses, Scaf = scaffolders, carp = carpenters, Plum = plumbers, Pain = painters)

Table 2. Handling material or tools—mean frequency of actions during the manipulation of different weights.

Type of work	Weight (kg) per action (50th percentile)	Mean frequency per hour weight distribution						
		<5 kg	5–10 kg	10–15 kg	15–20 kg	20–30 kg	30–50 kg	>50 kg
Bricklayers								
Using bricks requiring two hands	13.6	47.4	7.4	0.8	23.5	24.7	1.3	0
Using bricks requiring one hand in contract work	6.4	35.5	101.2	0.9	2.5	0.5	0	0
Making houses for multiple families	6.7	48.8	75.5	0.5	4.1	0.9	0.1	0
Building single-family houses	6.6	33.8	55.0	2.2	3.5	1.2	0.4	0.1
Scaffolders	17.8	13.4	15.4	7.1	8.0	16.7	4.5	0.5
Carpenters	14.3	0.6	9.9	9.5	5.2			
Plumbers	8.9	2.1	1.9	0.5	0.8	0.7	0.1	0
Painters	6.3	3.0	1.3	1	0.1			

multiple- and single-family houses (13.5% and 10.5%, respectively). The same applied to carpenters (4.6%).

Manipulation frequencies were of a general physiological importance, since they determined the acceleration forces that caused strain on the back muscles and on the hand–arm–shoulder system during lifting and releasing loads. These frequencies were high for all of the bricklayers and were in the range of 87.0 to 125.3 weight manipulations per hour, which represented nearly two exertions per minute. While the average weight of the bricks ranged from 6.4 to 13.4 kg, the weight for the scaffolders amounted to 17.8 kg, with a manipulation frequency of 63.1 actions per hour.

The recorded loads signified a high biomechanical pressure on the lumbar spine (figure 3).

With respect to the pressure exerted on lumbar disc L5/S1, the limit of the National Institute for Occupational Safety and Health (NIOSH), 3.4 kN, was often exceeded by scaffolders (5.6% of shift) and bricklayers working with bricks requiring two hands Br-th (3.8%). However, other bricklayers exceeded this limit only during 0.6% to 0.8% of their worktime. Plumbers and painters were only subject to high lumbar disc pressure for very short periods of time (0.1%).

If physical stress during work is to be evaluated sufficiently, more attention should be paid to the assessment of postures during kneeling, squatting, bending forward, and overhead work. During more than one-third of their shift, bricklayers worked in a bending position (figure 4), which had to be compensated for by the back muscles. While working on single-family houses (Br-of) and working with bricks requiring two hands (Br-th), the amount of bricklaying at floor- or knee-height ranged between 20.7% and 35.6% of the shift time, respectively. The painters (23.8%), plumbers (16.7%), and carpenters (9.8%) worked mostly in a kneeling and squatting position. For most of their work-time, the painters (18.3%), carpenters (9.5%), and plumbers (7.2%) worked with their hands in an overhead position and above shoulder level. The work positions of the scaffolders varied greatly, but mostly they worked in upright positions without extreme bending, kneeling, or squatting.

With the use of the mean weights handled, the applied observation instrument (AEB) allowed us to differentiate between bricklayers handling bricks requiring two hands and scaffolders and carpenters manipulating loads with two hands. However, the observation instrument did not allow the estimation of forces and pressure exerted by the hand–arm system on tools, such as claws, pipes, hammers, or brushes.

Apart from manipulating bricks requiring two hands, the bricklayers primarily handled bricks with the left hand and mortar with the right. Thus, when the parallel actions of the left and right hands are considered, the load frequency of each hand was about half of the total

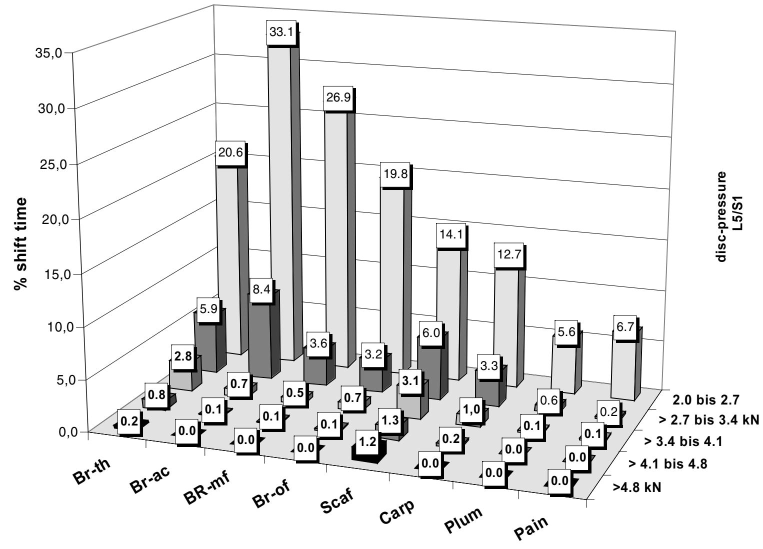

Figure 3. Biomechanical load pressure on the lumbar spine, segment L5 / S1, for different construction occupations (% of shift time). (Br-th = two-hand bricklayer, Br-ac = one-hand bricklayer, Br-mf = bricklayers building multiple-family dwellings, Br-of = bricklayers building single-family houses, Scaf = scaffolders, Carp = carpenters, Plum = plumbers, Pain = painters)

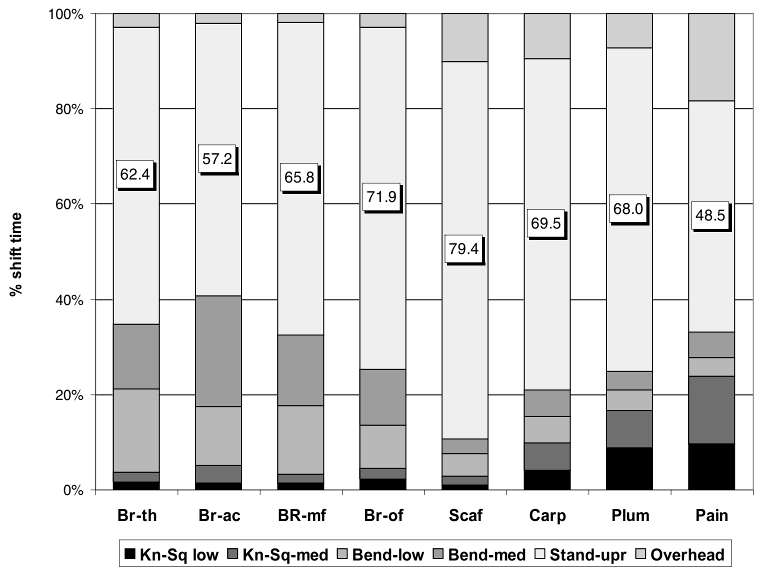

Figure 4. Work postures in percentage of shift time. (Br-th = two-hand bricklayer, Br-ac = one-hand bricklayer, Br-mf = bricklayers building multiple-family dwellings, Br-of = bricklayers building single-family houses, Scaf = scaffolders, Carp = carpenters, Plum = plumbers, Pain = painters, Kn-Sq-low = kneeling and squatting low, Kn-Sq-med = kneeling and squatting medium, Bend-low = bending low, Bend-med = bending medium , Stand-upr = standing up-right, Overhead = arms over head)

frequency. The results in figure 5 show that bricklayers using bricks requiring one hand manipulated between 87 and 125 bricks per hour, and most of these actions were carried out in a combination involving both hands. Therefore, these bricklayers manipulate a weight of >6 kg every minute. Even bricklayers handling heavier bricks requiring two hands (Br-th) showed a relatively high mean manipulation frequency of 98 actions per hour and a mean load per action of 13.6 kg. In figure 5 the median and the lower (10th) and upper (90th) percentiles characterize the distribution of the data. Depending upon the organizational structure of the construction site, the frequency distribution varied considerably [ie, Br-th: mean (median) = 98 (10th percentile=86 / 90th percentile=144) and Br-mf: mean (median) = 106 (10th percentile=67 / 90th percentile=229)].

The scaffolders had a more regular work pattern. They achieved a mean manipulation frequency of 63 actions per hour and a mean weight of 17.8 kg per action (table 2). These data were obtained from observations during the building of the scaffold, and, therefore, additional loading and unloading work or journey times to the construction site were not considered.

The relation between load–recovery time (ratio of recovery time divided by load time) and the load was a major indicator for defining the risk of repetitive strain injury of the hand–arm system. The load–recovery time relation was analyzed in our study in relation to the mean loads manipulated (figure 6). During most of the repetitive work of the bricklayers, carpenters, and scaffolders, the recovery time was never less than three times the load time (load–recovery time ratio >3) and never larger than nine times the load time (load–recovery time ratio <9). Obviously, with respect to the timing of the actions, the range of the load–recovery time, between 3 and 9, represented an intense work structure.

In contrast, even the demanding activities of the painters, plumbers, and bricklayers with machine support showed a load–recovery time in the range of 30-35. Therefore, under these circumstances, the work was less intense.

Discussion

The development of preventive measures for construction workers necessitates an analysis of workloads. Existing techniques for assessing the physical exposure to work-related musculoskeletal risks are manifold. Observational and direct methods, as well as self-reports and questionnaires, are used. Several techniques for assessing the load on the lumbar spine and postures already exist (15–18). Among these, the "lumbar motion monitor" from Marras (15) or the CUELA-HTR from Ellegast (17) in Germany were used in a universal field of different branches and tasks. For construction work, the following three criteria of assessment have to be considered from the viewpoint of morbidity: (i) lumbar spine pressure caused by external loads and the related load exposure, determined by frequency, variation, and time; (ii) joint and back muscle burden from different strenuous postures of kneeling, squatting, bending, twisting, and overhead work and their duration and recovery times; and (iii) higher burdens with respect to the upper extremities, their weights, and frequencies.

More interesting risk factors may exist, but the assessment effort becomes great if a representative number of studies is to be included. Observational methods and self-reports are limited with respect to their precision concerning the duration and frequency of higher loads and highly strenuous postures (18–20). In particular, construction work requires special methods for assessing physical exposure (9).

For this reason, we considered the AEB observation instrument, developed by Fleischer et al (11), to be appropriate for estimating load exposure at construction sites. Additional verifications in respect to the physical loads at construction sites can be obtained from the literature (22–25).

In an experimental study on construction sites (26), analysts recorded arm, trunk, and leg postures according to the category with two fixed-interval observational protocols. Observations were compared with measurements obtained with an electronic postural assessment system measuring upper-arm postures, knee flexion, and trunk flexion from video analyses. The agreement between the observational and reference methods was generally high.

In the case of retail store workers, a systematic observation method was based on the PATH (postures, activities, tools and handling) measurement method. It showed that it is also applicable to studies that require

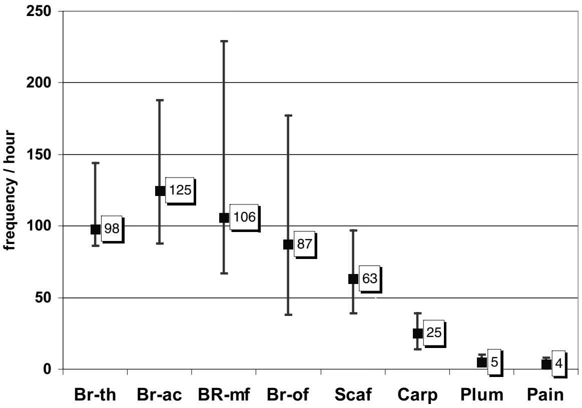

Figure 5. Frequency of handling weights of >1 kg with one or two hands. The median and the 10th and 90th percentiles are plotted. (Br-th = two-hand bricklayer, Br-ac = one-hand bricklayer, Br-mf = bricklayers building multiple-family dwellings, Br-of = bricklayers building single-family houses, Scaf = scaffolders, Carp = carpenters, Plum = plumbers, Pain = painters)

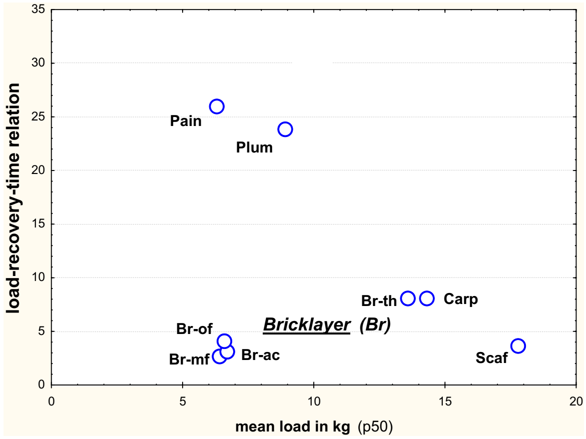

Figure 6. Relationship between load–recovery time and the mean loads manipulated. (Br-th = two-hand bricklayer, Br-ac = one-hand bricklayer, Br-mf = bricklayers building multiple-family dwellings, Br-of = bricklayers building single-family houses, Scaf = scaffolders, Carp = carpenters, Plum = plumbers, Pain = painters)

only fairly crude distinctions among biomechanical stressor variables (27).

Another study examining the work techniques of painters showed how strain to the arms and shoulders during sanding can be reduced (28).

Some fundamental restrictions exist with respect to the results of this study. The selection of the examined occupational groups should include a variety of possible load concentrations. Bricklayers have predominantly postural loads and repetitive hand–arm work. Some bricklayers are frequently subjected to physical loads on the back, and among these workers the volume discs of the lumbar spine are strained by the handling of particularly heavy stones. When erecting roof framing, scaffolders and some of the carpenters are subjected to particularly high loads from continuous work lasting several hours, and they handle heavy structural parts under difficult and dangerous conditions involving high accident risk. Fitters rarely have to lift heavy loads, but they undergo a particularly high proportion of compulsory physical postures. Painters spend particularly high proportions of their worktime on overhead work and in other compulsory postures and, in addition, must carry out repetitive hand–arm work.

A particularly difficult task, however, is the evaluation of the health risks that can result from the determined loads. Different guidelines have been designed to summarize the current state of knowledge (4, 5). An obligatory guideline is, however, lacking.

On construction sites, the workload is mainly determined by the weights handled, which partially or regularly exceed ergonomic recommendation limits (3). The highest loads were manipulated by scaffolders, who had to handle weights of >10 kg during nearly 15% of their worktime and had to manipulate five heavy loads of >30 kg per hour. Not only the musculoskeletal strain, but, from the physical point of view, also the energy consumption and heart rate proved that scaffolding is one of the most strenuous jobs in the construction business (29). The weight-lifting profile of carpenters was similar to that of scaffolders, but on a lower general level, since they spent much more of their worktime with craftsmanship. The bricklayers usually handled lower weights, but the trend towards working with bricks requiring two hands will ultimately alter this situation. In this case, in 7.1% of the shift time, weights between 10 and 50 kg were manipulated. On the other hand, bricklayers working on smaller houses must occasionally manipulate higher weights of ≥50 kg. These results are comparable with the data obtained in other studies (25, 30, 31).

The assessment of strain resulting from external loads and forces is an insufficiently solved problem. Epidemiologic data regarding different work-related musculoskeletal diseases are still lacking. General guidelines from Nordic countries (4) or from Dutch construction sites (5) summarize different ergonomic recommendations and ergonomic standards. The risk of damage to the lumbar spine depends on the biomechanical pressure and on the periods of exposure. The weight-lifting limit recommended by NIOSH amounts to a pressure of 3.4 kN on the lowest lumbar disc. The current work structure of scaffolders, bricklayers with bricks requiring two hands, and carpenters reveal a high lumbar risk. For elder men of about 50 years of age, Jäger et al (30) has recommended lower pressure forces between 3.2 and 2.3 kN. Nevertheless, all bricklayers have extensive periods of pressure between 2.0 and 2.7 kN, and such periods involve a lack of recovery time for the disc tissue and is definitely not suitable for women. This conclusion is supported by the observation that the load–recovery time was relatively short in comparison with that of other construction workers.

No ergonomic recommendations exist for assessing the correlation between long-term biomechanical stress and the exertion of the lumbar muscles. From a scientific point of view, it seems obvious that long-term muscular activity with bent postures causes back pain. Therefore, it can be concluded that, during bent postures, short load times should reduce back pain. However, at least with respect to bricklayers, painters, and plumbers, our experience with back pain profiles (8) renders this hypothesis questionable.

A search is also being made for solutions to help reduce the loads on the back in the building industry. Such solutions are more frequently needed than in many other industries, because the tradition of handling heavy loads has led to a higher tolerance among entrepreneurs and employees. The possibilities and difficulties involved in introducing new solutions are well known (33–36).

Therefore concrete load data are also required, together with medical and epidemiologic data, to render both the weight of the problem and the successes in reducing loads in the building industry measurable.

In conclusion, our investigation provides an overview of the most important causes of physical overloads to the musculoskeletal system in the construction industry. With around 30 persons in each case, the fundamental differences between the loads of the groups of activities were shown, but not the variety of the different loads from certain tasks of work within these groups of activities. In order to reduce the high pressure on the lumbar spine, more bricklaying machines and elevators should be introduced. In addition current scaffolds should be replaced by lighter constructions. The data provide a basis for a more purposeful prevention of musculoskeletal diseases, with functional and structural backgrounds in different fields of construction.

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