Occupational risks factors identified and interventions suggested by welders and computer numeric control workers to control low back disorders in two steel companies

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Abstract

Work-related low back disorders (WLBD) are common and expensive. This study assessed perceived workload and identified issues and possible improvements to reduce WLBD in 64 welders and 44 computer numeric control workers (CNC workers). Injury records were reviewed and a questionnaire was completed. Discomfort ratings and visual analogue scales were compared using one-way ANOVA with Fisher’s least-significant difference post hoc test. The annual incidence of recorded WLBD was lower for welders (3.4%) than for CNC workers (5.4%). On the other hand, the working-life incidences of reported WLBD and the point prevalences of low back pain were higher for the welders (55% and 27%, respectively) than for the CNC workers (36% and 16%). The discomfort scores for the low back region were higher than the scores for the other body parts. The weight manually handled [mean (S.D.)] by the welders [21 (6) kg] was lower than by the CNC workers [35 (11) kg]. Perceived exertion was strong for both groups [5 (1)]. For the welders, the postures, repetitions, and duration contributed more to the total effort than the movements and forces (p<0.035). For CNC workers, repetitions and duration contributed more to the total effort than postures, movements, and force (p<0.044). The workers identified relevant problems and possible improvements for their jobs. Recommended improvements included adjustable tables, stretching, and crane use by welders, and training, standing mats, clear limits, stable magnets, and less asymmetrical lifting by CNC workers.

Précis

This study evaluated reported occupational risk factors for WLBD among welders and CNC workers from two steel companies. A questionnaire was responded by 108 steel workers. The information presented can be used to design participatory ergonomic interventions aimed at reducing WLBD.

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1. Introduction

Work-related low back disorders (WLBD) are common and represent the most costly musculoskeletal disorder (AHRE, 2003; BLS, 2001; Nordin et al., 1997). WLBD are frequent in the steel industry (Dueker et al., 1994). For example, Udo and Yoshinaga (2001) reported that about 70% of the workers of the maintenance division of a steel mill had back pain during life. Masset and Malchaire (1994) studied WLBD in two steel companies using a checklist. The prevalence of low back pain was 66% for lifetime, 53% during previous year, and 25% during the previous week. Similarly, Hildebrandt et al. (1996) found a prevalence of low back symptoms in steel workers of 53% after 1 year of work.

WLBD control is an important issue in occupational health. Several epidemiological studies have demonstrated evidence that musculoskeletal disorders and workload are related (Bernard, 1997; Hales and Bernard, 1996). Bending, twisting, lifting heavy weights, and making forceful movements were shown to be related to WLBD (Frymoyer et al.,...
Welders and computer numeric control workers (CNC workers) frequently perform tasks involving the established risk factors for WLBD. For these reasons, it is important to implement WLBD control programmes in welding and CNC.

The cause of work-related musculoskeletal disorders is multifactorial (Kumar, 2001). We recently published the results of a questionnaire study on the relationship between personal risk factors (smoking, non-exercising, and being overweight) and WLBD in steel workers and nurses (Vieira et al., 2006a). In addition to the personal risk factors, the occupational risk factors are also an important aspect to consider on the control of WLBD. Perceived workload is an invaluable means to assess the occupational risk factors for WLBD, and the workers expertise is helpful in identifying suitable intervention measures (Hignett, 1996, 2001; Hildebrandt et al., 1996; Udo and Yoshinaga, 2001; Vieira et al., 2006b). For these reasons, the objectives of this paper were (I) to present the results on the perceived occupational risk factors (perceived workload and reported physical demands) by welders and by CNC workers in two steel companies, (II) to report the problems identified by the workers as potential causes of WLBD in their jobs, and (III) to introduce potential improvements suggested by the workers to reduce the incidence of WLBD in their jobs.

2. Materials and methods

2.1. Epidemiological study

A retrospective study (1999–2003) of WLBD claims (low back disorders registered by a workers compensation agency) was conducted in steel companies A and B. The epidemiological evaluation was performed using previously recorded information from the Workers Compensation Board and from internal records of injuries for these worksites. Only new cases were considered, the re-injuries were not included in the calculations. In addition, the worksites were asked to provide information about the number of workers per job per year from 1999 to 2003. The WLBD claims were reviewed, including injury date and job of the injured workers.

2.2. Questionnaire survey

After the retrospective study, the welders of company A and the CNC workers of company B completed the questionnaire (Vieira et al., 2005, 2006a, b). The questionnaire included questions on the workers’ personal traits, life style, history of WLBD, perceived occupational factors, and the following scales:

- **The 10-point body part discomfort index** (Corlett and Bishop, 1976): A body diagram on which the workers identified and rated areas of perceived discomfort by the end of the shift on a 10-point severity scale from ‘no discomfort’ (1) to ‘very uncomfortable’ (10).

- **The Borg's 10-point scale of perceived exertion** (Borg, 1962, 1982, 1990): A ratio-categorical scale on which the workers rated their job exertion from ‘nothing at all’ (1) to ‘maximal’ (10).

- **100-millimetre visual analogue scales (VAS)** (Huskisson, 1983; Vieira et al., 2005): Horizontal lines on which the workers marked their job required efforts for posture, movements, repetitions, force, and duration between ‘no effort’ and ‘maximal effort’.

2.3. Sample

One-hundred and eight male workers (64 welders and 44 CNC workers) from the steel companies A and B completed the questionnaire. The sample included, respectively, 78% (64/84) and 94% (44/45) of the full time welders and CNC workers in these worksites. The participation rates were more than the minimal (70%) recommended by NIOSH (Bernard, 1997). The sample characteristics are presented in Table 1.

There were no differences between the welders and CNC workers in height, weight, and body mass index. However, the welders were on average 10 years older than the CNC workers (p<0.001). The BMI is a measure of body fat based on height and weight. Depending on the value the person is considered underweight (BMI<18.5), normal weight (BMI from 18.5 to 24.9), overweight (BMI from 25 to 29.9), or obese (BMI≥30) (National Heart, Lung, and Blood Institute, 2005). Thus, both welders and CNC workers were overweight.

2.4. Jobs

Steel company A manufactures structural steel for the construction and oil industries. Steel pieces welded at steel company A included beams, plates, frames, and structural steel components. The welders received the pieces, inspected, lifted, and carried smaller pieces from stacks to workbenches approximately 3 m apart, welded pre-fitted joints on handrails and structural pieces using wire weld, grinded, and air-chipped welds, replaced wire reel and performed housekeeping. Larger pieces were moved using

<table>
<thead>
<tr>
<th>Job (n=108)</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Body mass index (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welders (n=64)</td>
<td>37 (13)</td>
<td>177 (10)</td>
<td>81 (18)</td>
<td>26 (5)</td>
</tr>
<tr>
<td>CNC workers (n=44)</td>
<td>27 (5)</td>
<td>178 (1)</td>
<td>83 (13)</td>
<td>26 (4)</td>
</tr>
<tr>
<td>Total (n=108)</td>
<td>33 (11)</td>
<td>177 (9)</td>
<td>82 (16)</td>
<td>26 (5)</td>
</tr>
</tbody>
</table>

Table 1 Mean (S.D.) of age, height, weight, and body mass index of the welders and computer numeric control workers (CNC workers)

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cranes and frequently caused the workers to assume awkward postures to get to the joints to weld, sometimes in small and confined spaces. After the job was completed, the pieces were moved to sand blasters. The work shift was 10 h, 4–5 days/week; there was monthly rotation between day and night shifts. The day shift was from 5:30 a.m. to 4 p.m. with 30 min lunch from 10:30 a.m. to 11 a.m., and the night shift was from 4:30 p.m. to 3 a.m. with 30 min dinner from 9:30 p.m. to 10 p.m. Fig. 1 shows a welding job in kneeling posture.

Steel company B processes blades for tractors, snowploughs and other machines. The CNC job at company B required to programme, set clamps, load, tighten up and untighten blades to machines, unload machines manually or using cranes, inspect and measure the blades, and grind the edges and holes (grind, flip, grind). When using cranes, a magnet was attached to the blade and then it was pushed or pulled towards the table, bench, or blocks on the floor. The blades were pushed or pulled on rollers while on machine tables. The machines drilled, milled, or punched holes. The blades were flipped over for cleaning the shavings out then stacked and moved to the next station. At the end of the shift, the workers cleaned-up shovelling out the shavings. The work shift was 12 h/day, 42 h/week; there was monthly rotation between day and night shifts.

Fig. 2 shows a CNC worker loading and unloading a drilling machine.

2.5. Data collection and ethics

This study was approved by the University Human Research Ethics Board. Participation was voluntary. The workers were informed about the study by a recruitment poster. Those who decided to participate informed the foreman who sent them to fill out the questionnaire. The questionnaires were completed during the shifts at the worksites in the presence of the researcher. The volunteers received explanations about the study objectives and were informed of their right not to participate and to withdraw at any time with no consequence to them. All questions were answered, and the questionnaires were handed out after a signed informed consent was obtained.

2.6. Data analysis

There is some confusion on the use of the epidemiological terms of incidence and prevalence. In this study we use the following definitions: (I) annual incidence is the number of new cases recorded in a year divided by the...
number of workers in that year; (II) working-life incidence is the number of workers that reported to have had at least one episode during their working-life divided by the number of workers questioned; (III) point prevalence is the number of workers reporting to have the condition at that moment divided by the number of workers questioned (Portney and Watkins, 2000). The annual incidences of WLBD claims (average percentage of workers that had a WLBD claim recorded by the workers compensation board between 1999 and 2003) were calculated dividing the numbers of claims per year (excluding re-injuries) by the number of workers per year. Similarly, the working-life incidences of WLBD (explained for the workers as ‘low back pain interfering with daily activities and work during the working-life’) and point prevalences of low back pain (percentage of the workers that reported to suffer pain on the lumbar spine region at the moment of questionnaire completion) were calculated dividing the frequency by the number of workers that completed the questionnaire.

The five VAS results were added to calculate the total effort required by the jobs. Each VAS was presented as a percentage of the total effort and the total effort was presented as a percentage of the maximum possible (500 mm). The data analysis incorporated descriptive statistics and comparison of means using the SPSS statistical package for windows (SPSS Inc., Chicago, IL). Numerators and denominators were given in parenthesis for percentages.

The homogeneity of variances was analysed using Levene statistic. The sample characteristics (age, height, weight, and BMI) and the discomfort ratings of welders and CNC workers were compared using independent-samples t-test. The body parts discomfort ratings, and the five VAS, were compared using one-way ANOVA with Fisher’s least-significant difference post hoc test. Differences were considered significant when \( p < 0.05 \).

3. Results

3.1. Frequency of WLBD in the welders and CNC workers

In total (including re-injuries), there were 37 WLBD claims, from 1999 to 2003, among the 144 workers in company A (welding, fitting, and CNC), and 39 WLBD claims in the 95 workers in company B (CNC, cutting, and heat treatment). The workers with the highest number of WLBD claims in company A were welders [38% (14/37)], fitters [16% (6/37)], and fitter apprentices [11% (4/37)], while in company B they were CNC workers [44% (17/39)], cutting workers [36% (14/39)], and heat treatment workers [21% (8/39)]. The direct cost of WLBD claims was C$ 24,471 to company A and C$ 69,997 to company B. The annual incidences of WLBD claims was 3.4% (1.85/55) for the welders and 5.4% (2.17/40) for the CNC workers; the working-life incidences of WLBD were 55% (35/64) for the welders and 36% (16/44) for the CNC workers, and the point prevalences of low back pain were 27% (17/64) for the welders and 16% (7/44) for the CNC workers. Musculoskeletal pain in some body part at the time of questionnaire completion was reported by 44% (28/64) of the welders and 27% (17/64) for the welders and 16% (7/44) for the CNC workers. From those, 61% (17/28) and 58% (7/12), respectively reported low back pain. Thus, the point prevalence of musculoskeletal pain in the total sample was 37% (40/108).

Fig. 3. Discomfort scores (mean and S.D.) in different body parts at the end of the welders (n = 64) and computer numeric control workers (CNC workers, n = 44) shifts (1 = no discomfort; 10 = maximum discomfort).
3.2. Body part discomfort by the end of the shift

Fig. 3 presents the discomfort at the end of the shift in different body parts.

There were differences between the discomfort scores given to the different body parts by both welders and CNC workers (Table 2).

The low back received higher discomfort scores (verbal correspondent of ‘moderate discomfort’) than all other body parts for both welders and CNC workers (Table 3).

The discomfort scores given by the 64 welders to the low back region were higher than the scores given by the 44 CNC workers (mean difference \( \mu = 1.6 \), \( p = 0.004 \)).

3.3. Manual materials handling and rates of perceived physical exertion

Table 4 presents the number of times per hour that the welders weld, grind, and chisel, and that the CNC workers lift, push and pull during the shift.

The perceived exertion rated on the Borg’s 10-point scale was strong for both groups. The reported weights handled by the welders was lower than by the CNC workers, but the perceived exertion and the total effort required were not different between the groups (Table 5).

The total effort required by the jobs on the VAS for welding and CNC were not significantly different. The maximum possible was 500 mm representing the sum of the five 100 mm VAS for postures, movements, repetitions, force, and duration.

Fig. 4 presents the percentages of contribution of the different variables to the total effort required by the jobs. For the welders, the postures, repetitions, and duration contributed more to the total effort than the movements and forces \( (p<0.035) \). For CNC workers, repetitions and duration contributed more to the total effort than postures, movements, and force \( (p<0.044) \). The contribution of postures to the total effort by welders was higher than for CNC workers \( (p = 0.001) \). On the other hand, the contribution of forces was lower for welders than for CNC workers \( (p = 0.034) \).

3.4. Problems related to and suggested improvements to reduce WLBD

Table 6 presents the issues reported as related to WLBD in the jobs and the workers’ suggestions.
4. Discussion

In addition to determining the reported point prevalence of low back pain and working-life incidence of low back disorders, this study evaluated the potential for using a questionnaire for job evaluations, WLBD risk assessment, and as a potential tool for evaluating subsequent interventions. Some aspects and questions in the questionnaire were useful for evaluating the job and risks, while other portions were not particularly helpful. These characteristics are specifically discussed on the following sections.

4.1. WLBD rates, body part discomfort and manual materials handling

The CNC workers had lower working-life incidence of reported WLBD and point prevalence of reported low back pain than the welders. On the other hand, the CNC workers had higher annual incidence of recorded WLBD claims. A possible explanation for these findings is that the CNC workers were younger and it may also be due to high turnover in steel company B. The reported weights lifted represented increased risk for the welders and especially for the CNC workers. It may also partially explain the higher annual incidence of WLBD claims in CNC workers and the trends observed in the discomfort scores where the low back received the highest scores by both groups.

The scores given by the welders were higher than by the CNC workers; it may be related to the type of exertion performed where the CNC workers lifted heavier loads for short periods of time while the welders sustained awkward postures with somewhat lighter loads for longer periods of time. These observations are corroborated by the VAS findings and may point toward different mechanisms of discomfort and injury precipitation for the welders and CNC workers. The discomfort reported by the welders may be related to temporary postural syndromes (McKenzie, 1981) while for the CNC workers it may be attributable to overexertion (Kumar, 1994) possibly causing more permanent injuries even though less frequently. The combined assessment of both recorded rates of WLBD, reported low back pain, and reported working-life rate of WLBD was important and useful to understand their relative contributions and roles on risk assessment as per the discussion above.

Company A policy stated that 23 kg was the limit for manual lifting, and it was the workers' responsibility to utilize the cranes to lift/move heavier material. Company B policy was not clear; they required workers to use cranes to lift over 27–36 kg or over 1.83 m long, and to use flipping
The reported weights lifted by CNC workers were higher than NIOSH proposed limit. In addition, the lifting conditions for welders and CNC workers were not optimal. Other studies have reported more stringent limits for lifting. Chaffin and Park conducted a 1-year longitudinal study about the relationship between WLBD and occupational lifting, including 411 subjects from 103 jobs (Chaffin and Park, 1973). They found increased risk of WLBD when workers lifted more than 16 kg. When the horizontal distance of the load was more than 50 cm from the ankle, lifting loads form 9 to 34 kg represented increased risk of WLBD. Heavy lifting, using jack hammers or machine tools, and motor vehicle operation were demonstrated to be risk factors for ‘severe low back pain’ in males 18–55 years old (Pope et al., 1985).

4.2. Rates of perceived physical exertion (Borg scale and VAS)

The Borg scale ratings of perceived exertion are correlated with heart rate \( r = 0.80–90 \), minute ventilation and respiratory rate \( r = 0.76–0.97 \), and blood lactate during continuous or intermittent exercise on bicycle and treadmill and also during arm or leg work (Borg, 1962, 1982, 1990; Carton and Rhodes, 1985). The exponential (1.6) relationship between physical work and perceived exertion is taken into account by the Borg’s 10-point scale where more points in the ratio scale are provided for higher semantic intensity expressions in the categorical correspondent. In this study, the Borg scale ratings alone (verbal equivalent of strong for both groups) did not differentiate between the welding and CNC jobs, nor did the percentage of total effort on VAS. However, the specific VAS for posture, movement, repetition, force, and duration were more sensitive and helpful in identifying specific risks within the jobs as discussed on the next paragraph.

The VAS results are in agreement with the observed job demands, described job tasks, and helped to understand the different mechanisms of discomfort and injury as discussed in the previous section. Repetitions and durations are an issue to be considered in both jobs. On the other hand, the postural requirements of the welding job are higher than for the CNC job, while the force requirements are higher in the CNC workers’ job in relation to the welders’ job. These latter two variables allowed differentiating the critical demands of the jobs. This new method of analysing the physical effort in relation to its different components was useful. Additional research on its use and applications is needed because this method of perceived physical demands analysis is new.

Perceived exertion is related to kinesthetic sensitivity, proprioception, ligament, joint, tendon and muscles cues (mechanoreceptors), and to psychological variables such as personality, motivation and psychometric aptitude. Physiological strain of active muscles have higher impact on the perceived exertions at lower levels (work intensity below lactate threshold) such as the levels most often observed.
during occupational activities, as opposed to high level aerobic exercises where heart rate and blood lactate are better predictors of perceived exertion (Carton and Rhodes, 1985).

4.3. Problems and suggestions from the steel workers

The importance of considering the workers’ concerns and suggestions was previously demonstrated (Hildebrandt et al., 1996; Udo and Yoshinaga, 2001). The workers are rightly concerned about their working postures (Vieira and Kumar, 2004). The risk of back disorders in automobile assembly workers (95 cases and 124 referents) was associated with mild (OR 4.9, 95% CI 1.4–17.4) and severe trunk flexion (OR 5.7, 95% CI 1.6–20.4), and with lateral flexion or rotation (OR 5.9, 95% CI 1.6–21.4) (Punnett et al., 1991). Workers maintaining severe trunk flexion for at least 10% of the working cycle were approximately 9 times more likely to have back disorders than workers maintaining neutral posture (p = 0.003) (Punnett et al., 1991). Asymmetric lifting, as pointed out by the CNC workers, was demonstrated to be significantly associated with prolapsed lumbar disc (OR 6.1) (Kelsey et al., 1984).

Heavy lifting, use of vibrating equipment, driving, and tobacco consumption were reported to be risk factors for ‘severe low-back pain’ in men between 18 and 55 years old [lifetime incidence of 23.6% (288/1221)] (Frymoyer et al., 1983). Forty-four per cent (163/368) of the subjects with ‘no low back pain’, 48% (269/565) of the subjects with ‘moderate low back pain’, and 54% (155/288) of the subjects with ‘severe low back pain’ lifted 20 kg or more at work. Tobacco consumption, overweight, and sedentary life style were also found related to low back pain in our study (Vieira et al., 2006a).

Overall, the recognized occupational risk factors for WLBD are heavy physical work, static and awkward work postures, prolonged standing and sitting, frequent bend and twisting, lifting, pushing, and pulling, repetitive work, and vibration. The psychological and psychophysical risk factors include work satisfaction and support. Finally, individual risk factors are age and gender, posture, strength, fitness, spinal mobility, smoking, and overweight (AHRE, 2003; Andersson, 1991; Bernard, 1997; BLS, 2001; Chaffin and Park, 1973; Nordin et al., 1997; Picavet and Schouten, 2003; Pope et al., 1985; Punnett et al., 1991; Vieira and Kumar, 2004, 2006).

Both companies require workers to use crane to lift/move heavier materials. However, the lack of a systematic policy enforcement system in both companies resulted in non-compliance even though the worker knew they should use the equipment and recognized that by doing so the risk of injury would decrease. When evaluating the reasons why the equipment was not always used some issues became apparent. One was the fact that there was a ‘macho’ culture among the workers. Thus, a safety culture needs to be reinforced in both work places to modify behaviour along with policy enforcement. Another issue was the fact some cranes, specially the ones available for the welders, were not well maintained and required significant effort to attach and detach the material from the lift. For these reason, some workers only used the crane when the pieces could not be lifted manually.

The workers concerns and suggestions are related to published guidelines and risk factors previously determined by researchers, safety professionals and ergonomists. The workers’ opinions are helpful and should be taken into account when designing workplace interventions. The suggestions provided by the workers in Table 6 were meaningful and important; however, they were too general. More specific recommendations are needed to reduce the risk of low back disorders. This shows the important role of ergonomists in collecting the information, interpreting their meaning and translating the general suggestions into specific recommendations. For example, the suggestion ‘Improve the workstation set up and space’ is relevant. However, further development is required to transform the suggestion into meaningful interventions to avoiding unnecessary steps (e.g. lifts, lowers, carries) such as remove unnecessary material and equipment from working area, provide storage space for the tools so that they are not left on the ground and reached for every time the worker goes from welding to chiselling or grinding. In addition, the workstations (welding tables) should be placed closer to the ‘cut-to-shape’ tables to reduce the transportation distances.

In relation to the CNC workers, they mentioned the problem of ‘standing on bare concrete’ and suggested ‘installation of fatigue resistance mats’. However, we believe that the problem was standing for the entire 12-hour work shift, and the appropriate intervention would be to provide stools for allowing alternations between seated and standing postures, for example, while the machine was drilling holes into the steel blades. In addition, the increase of the heights of the CNC tables and CNC machine headroom would reduce the amount and duration of trunk flexion required. Future studies could compare worker-based assessments with certified ergonomists’ assessment to evaluate how similar the recommendations would be or how they add to the process.

5. Conclusions

This study presented issues may be leading to high incidences of WLBD in welding and CNC in two steel companies. Many established risk factors such as awkward postures, lifting, forceful movements, and heavy workloads were present in the jobs. The questionnaire used was practical and useful to initiate a job evaluation. No studies using such a combination of measures to evaluate steel workers were found making the present evaluation unique. The Borg scale was not sensitive to differentiate between the jobs. On the other hand the VAS were helpful in identifying specific risks that need to be addressed in the jobs (i.e. welders’ postures and CNC workers’ forces). The workers had good insights into the problems at their jobs.
and helped identifying risks for WLBD and possible improvements. The information provided by the workers is relevant for assessing and redesigning the jobs, illustrating how the steel workers can significantly contribute to this process. However, their suggestions were general and needed to be refined to arrive at specific recommendations. The information presented can be used to design participatory ergonomic interventions aimed at reducing WLBD.

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