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Applied Ergonomics 38 (2007) 617–624

APPLIED ERGONOMICS

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Musculoskeletal problems in Iranian hand-woven carpet industry: Guidelines for workstation design

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Received 25 August 2005; accepted 11 June 2006

Abstract

Long hours of static work with awkward posture at traditionally designed looms can cause high prevalence of musculoskeletal disorders (MSDs) among carpet weavers. A comprehensive study was conducted in this industry with the objectives of determination of MSDs symptoms prevalence; identification of major factors associated with MSDs symptoms in carpet weaving occupation; and development of guidelines for weaving workstation design. In the present paper, this ergonomics study is presented.

The study consisted of two phases. In the first phase, MSDs symptoms in nine Iranian provinces were surveyed by questionnaire among 1439 randomly selected weavers. Working posture and weaving workstations were ergonomically assessed as well. The results of this phase revealed that symptoms from the musculoskeletal system occured in high rate among weavers with the prevalence significantly higher than that of the general Iranian population ($P<0.001$). It was found that the majority of ergonomics shortcomings originated from ill-designed weaving workstation. Based on the findings, some general guidelines for workstation design were presented. In the second phase, considering the general guidelines, an adjustable workstation was designed and constructed. To develop quantitative guidlenes for optimizing workstation set-up, in the laboratory, nine sets of experimental conditions were tested, and working posture and weavers' perceptions were measured. The results of this lab work showed that working posture was acceptable for both the researchers and the weavers when the weaving height was adjusted 20 cm above the elbow height and a high seat with forward slope was used.

By combining the results of the two phases, guidelines for weaving workstation design were presented. In this ergonomics-oriented workstation, loom is vertical. Seat, loom and weaving heights are adjustable. There is enough leg room under the loom. The seat with 10° forward slope is adjusted 15 cm above the popliteal height of the weaver. Weaving height is set at 20 cm above the elbow height. It is believed that the recommended workstation improves working posture and results in reduced postural stress on weavers' bodies and, consequently, reduced prevalence of MSDs symptoms.

Keywords: Hand-woven carpet industry; Musculoskeletal problems; Weaving workstation design

1. Introduction

Musculoskeletal disorders (MSDs) are a common health problem throughout the world and a major cause of disability. The economic loss due to such disorders affects not only the individual but also the organization and society as a whole (Kemmlert, 1994). At the present time, MSDs is one of the most important problems ergonomists are encountering in the workplace all over the world (Vanwonterghem et al., 1996). In many countries, the prevention of work-related MSDs (WMSDs) has become a national priority (Spielholz et al., 2001).

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0003-6870/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apergo.2006.06.005

WMSDs is a worldwide concern and distributed among both industrialized countries (ICs) and industrially developing countries (IDCs). In IDCs, the problems of workplace injuries are extremely serious (Shahnavaz, 1987). Poor working conditions and the absence of an effective work injury prevention program in IDCs has resulted in a very high rate of MSDs (Jafry and O'Neill, 2000). According to Coury (2005), in spite of the fact that WMSDs have had increasing trend during the last decade in IDCs, research in prevention has appeared insufficient.

In IDCs, small-scale industries comprise a high percentage of all factories and manufacturing establishments. The preponderance of small-scale industries and their employment of a substantial percentage of the work force in IDCs necessitate greater attention towards the health and safety problems of this sector (Reverente, 1992). WMSDs prevention and improvement of working conditions of small-scale industries in IDCs will have considerable effect on promoting and sustaining the quality of people's life and would result in productivity enhancement.

Carpet hand weaving is a common practice in countries such as Iran, China, Turkey, India, Pakistan, Russia, Egypt, Nepal and Afghanistan. In Iran, hand-woven carpets are produced nearly always in home-based workshops categorized as informal small-scale industry, often organized around families and done in homes. Hand-woven carpets are the most important Iranian non-oil exported goods and has an outstanding place in the country economy from the viewpoint of its share of 1% in GNP (Mahdavi, 2000) and employment. In Iran, nearly 2.2 million full time and part time weavers are working (Sobhe, 1997) and about 8.5 million of people directly or indirectly live on hand-woven carpet industry (JSO, 1998).

Carpet weaving is one of the most tedious professions, requiring long hours of static work (Ghvamshahidi, 1995) and can be a high-risk occupation for developing MSDs as awkward posture, repetitive movements and contact stress are common (Choobineh et al., 2004a). In a study on carpet mending operation as a part of carpet industry, Choobineh et al. (2004b) found that the working conditions were poor and awkward working postures were very common. They reported high rate of musculoskeletal problems in knees, back and shoulders of the carpet menders.

In spite of national importance of hand-woven carpet industry in Iran and its potential fruitful impact on overall economy of the country, there have been few ergonomics studies of weavers' work. In this paper, a comprehensive ergonomics study, which was carried out in the Iranian hand-woven carpet industry, is described; musculoskeletal problems and major factors associated with symptoms in carpet weaving occupation are presented; and guidelines for weaving workstation design are proposed.

This study consisted of two phases, which are described separately.

2. Phase I

2.1. Materials and methods

In the first phase, musculoskeletal symptoms in more than 1000 active weaving workshops in rural and urban districts of nine Iranian provinces were surveyed and working posture and weaving workstations were ergonomically assessed (Choobineh et al., 2004c). Totally, 1439 randomly selected weavers who agreed to be studied participated in this phase of the study. A questionnaire and a checklist were used to collect required data from each sample and each workstation. The questionnaire contained questions about personal and workshop details together with General Nordic Questionnaire (Kuorinka et al., 1987). The checklist consisted of two parts including (a) weaving posture assessment checkpoints devised based on RULA technique (McAtamney and Corlett, 1993), by which posture of upper and lower arms, neck, trunk and legs were assessed and (b) weaving workstation assessment checkpoints regarding seat type, seat padding and leg space.

All workshops were visited and the questionnaires were completed by interviewing the weavers. In order to estimate the reliability of the responses to questions in the questionnaire, test-retest method was applied (Colin, 1995) on 5% of the study population. The results of reliability test revealed that for almost all variables correlation coefficients were acceptable for questionnaire administration (i.e., correlation coefficient for subjective and quantitative variables was greater than 0.65 and 0.9, respectively).

Chi-square test was used to assess univariate associations between individual and ergonomics variables and reported musculoskeletal symptoms. Multiple logistic regression analysis was performed for each outcome retaining the individual and ergonomics variables in the models to adjust for potential confounding.

2.2. Results

The results of the first phase of the study, as shown in Table 1, demonstrated that the most commonly affected regions among the weavers were shoulders (47.8%), lower back (45.2%), wrists/hands (38.2%), upper back (37.7%), neck (35.2%) and knees (34.6%). Eighty-one percent of the weavers had experienced some kind of symptoms and pain from the musculoskeletal system felt at some time in the last 12 months.

Working posture assessment of weavers showed that high percentage of observed postures of upper arm, neck and trunk deviated from neutral posture. In 70.3% of all cases, legs got score 2 (i.e., awkward posture) indicating that weavers sat on the ground or a piece of wood strip in cross-legged or folded knees position (Fig. 1).

Table 2 presents significant ergonomics factors associated with musculoskeletal problems for each body region.

Table 1
Frequency of reported symptoms in different body regions of the weavers in the 12 months prior to the study ($n = 1439$)

Body regions	%
Neck	35.2
Shoulders	47.8
Elbows	19.2
Wrists/Hands	38.2
Upper back	37.7
Lower back	45.2
Thighs	16.0
Knees	34.6
Legs/feet	23.7

Fig. 1. Weavers are weaving at a vertical loom. They are sitting on a piece of wood strip (called lumbar) in cross-legged position. Posture of different parts of body is deviated from neutral (Choobineh et al., 2004c).

The significant factors were the result of a multiple logistic regression analysis performed to adjust for potential confounding. As shown in Table 2, several factors relating to the ergonomics conditions were found to be important in relation to musculoskeletal problems, especially loom type, working posture, daily working time and seat type. It is to be noted that neck, trunk and leg postures were not mutually exclusive and they could be considered loom type-related, since horizontal loom, for instance, always resulted in bent neck and trunk postures. For this reason, they are taken out of the table, but to show their significance, they are presented in the table footnote. Musculoskeletal symptoms were also associated with individual factors including age, sex, marital status and job tenure.

Based on the results of this phase, the following recommendations were developed as general ergonomics guidelines for weaving workstation design oriented towards eliminating constrained, awkward postures.

(a) Looms should be in vertical type.
(b) Loom and weaving height should be adjustable for improving neck, back, shoulder and arm working postures.
(c) Weaving workstation should be equipped with appropriate seat (chair or bench).
(d) There must be sufficient clearance for legs movement under the loom to accommodate both small and large weavers.

Taking into account the developed guidelines, accompanied by a thorough review of the looms currently in use in the weaving industry, a prototype for a weaving workstation was designed and constructed (Fig. 2). Although working posture and workstation adjustability were improved considerably in this prototype, further work seemed to be needed to develop quantitative guidelines for optimizing working posture.

3. Phase II

3.1. Materials and methods

In the second phase of the study, the prototype of weaving workstation was used (Choobineh et al., 2004d). In the laboratory, nine sets of experimental conditions were tested. Measurements were made of weavers' working postures and their subjective experience while they worked at the designed workstation under the nine sets of experimental conditions of the main design parameters of "weaving height" and "seat type" (Choobineh, 2004).

Fifteen healthy male and 15 healthy female professional weavers participated in this phase of the study. By a factorial design methodology, at the adjustable experimental workstation, the weavers performed their normal weaving task in nine experimental sessions of 45 min followed by breaks of 15 min. In each session, one of the nine sets of experimental conditions was presented. Each participant completed the experiments in 2 days. The sets of experimental conditions were presented in random order to counterbalance the carry-over and order effects. In this lab work, which was conducted in a period of 60 working days, the following variables were studied.

3.1.1. Independent variables

The weaving heights (height of the location of knotting) tested, covering the range of weaving height observed in the industry, were related to the individual elbow height of the weaver:

- 10 cm above elbow height (+10 cm),
- 20 cm above elbow height (+20 cm),
- 30 cm above elbow height (+30 cm).

The seat types tested were as follows:

- conventional seat: a flat seat with height equal to the weaver's popliteal height,
- high seat: a 10° forward-sloping seat with height equal to the weaver's popliteal height plus 15 cm,

Table 2
Models indicating ergonomics factors with the strongest influence on musculoskeletal symptoms in different body regions of weavers[a] (Choobineh et al, 2004c)

Body region	Factors retained in the model		
	Factors	Odds ratio	P
Neck[b]	Loom type	1.98	<0.001
	Seat type	1.95	<0.05
	Daily working time	1.48	<0.01
Shoulders[c]	Seat type	2.98	<0.001
	Type of knots	1.65	<0.001
	Daily working time	1.37	<0.01
Elbows	Daily working time	1.67	<0.001
	Type of knots	1.61	<0.01
Wrists	Loom type	1.54	<0.01
	Daily working time	1.48	<0.01
Upper back[d]	Loom type	2.10	<0.001
	Seat type	1.75	<0.05
	Daily working time	1.73	<0.001
Lower back[e]	Loom type	2.75	<0.001
	Seat type	1.71	<0.05
	Daily working time	1.31	<0.05
Thighs[f]	Seat type	3.09	<0.05
	Loom type	2.06	<0.001
	Daily working time	2.00	<0.001
Knees[g]	Loom type	1.51	<0.05
	Daily working time	1.35	<0.05
Legs[h]	Loom type	2.49	<0.001
	Daily working time	1.86	<0.001

[a]The factors considered in the regression models were sex, age, job tenure in weaving, daily working time, weekly working days, marital status, number of children, loom type, type of knots, seat type, seat padding, neck posture, trunk posture, arm posture, leg posture and leg clearance.
[b]As well as neck posture (OR = 1.79 and $P<0.01$).
[c]As well as trunk posture (OR = 1.67 and $P<0.01$).
[d]As well as trunk posture (OR = 2.50 and $P<0.001$).
[e]As well as trunk posture (OR = 1.65 and $P<0.01$).
[f]As well as leg posture (OR = 1.77 and $P<0.01$).
[g]As well as leg posture (OR = 1.45 and $P<0.01$).
[h]As well as leg posture (OR = 1.39 and $P<0.05$).

- traditional seat (bench): a flat seat currently used in most weaving workshops. The weaver sat on the bench in cross-legged posture.

3.1.2. *Dependent variables*

Working posture was measured by WEPAS, a two-dimensional video-based system for recording and analyzing weaving posture developed based on image processing technology (Choobineh et al., 2004e). The following dependant variables, which were defined precisely in Choobineh et al. (2004d), were calculated:

- head inclination (HI),
- neck inclination (NI),
- trunk inclination (TI),
- arm angle (AA),
- elbow angle (EA).

In each experimental condition, the subject performed the weaving task for approximately 15 min to become accustomed to the arrangement. The subject's posture was then recorded for 10 min. Then, she/he continued working for further 20 min to complete the session of 45 min. For postural analysis, averages of the postural variables over the 10 min of recording were used. To compare the nine sets of experimental conditions, deviation of postural angles from the neutral posture was used.

Weavers' perceptions were recorded by a questionnaire containing three parts (rating techniques):

(A) perceived posture,
(B) localized postural discomfort,
(C) judgment on workstation adjustment.

The data on working posture and perceptions were statistically tested to determine differences between sets of

Fig. 2. The prototype of the designed loom and workstation. In this workstation, legs are well supported, there is enough clearance under the loom for legs, and overall body posture is acceptable (Choobineh et al., 2004c).

experimental conditions. Postural variables were tested by ANOVA for repeated measures and perceptions were tested by Friedman test.

3.2. Results

The results clearly showed several major effects of workstation adjustment on postural variables (Fig. 3). Firstly, as the weaving height increased, head, neck and trunk got more upright. Secondly, as the weaving height decreased, shoulders got a more appropriate posture and close to neutral. Thirdly, weaving height +20 cm resulted in a better elbow posture and closer to neutral. It was concluded that in weaving operation, weaving height +20 cm could be the suitable compromise in which postures of head, neck, trunk and shoulders seemed not to be severely deviated from neutral and the posture of elbows was appropriate.

Regarding seat type, based on the results, both conventional and high seat with forward slope could be recommended as they had overall positive effects on posture of different body regions. However, the high seat caused slightly less trunk inclination, increased trunk-thigh angle and consequently increased lordosis in the lumber region.

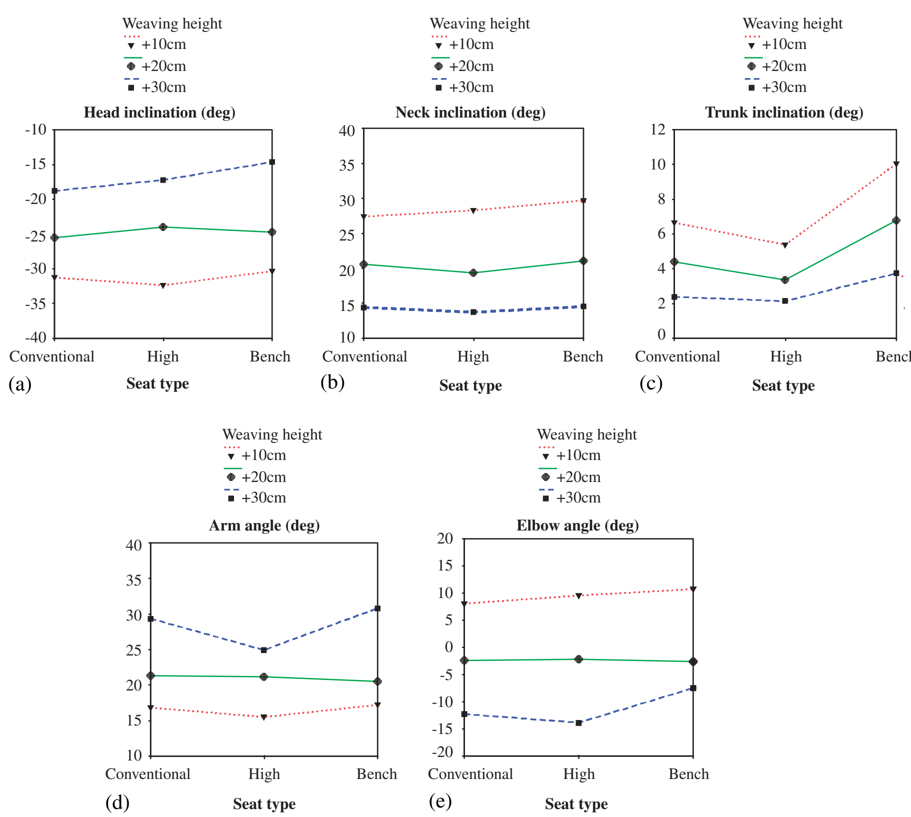

Fig. 3. Postural variables in the nine experimental conditions (average group values, $n = 30$). (a) Head inclination, (b) Neck inclination, (c) Trunk inclination, (d) Arm angle, and (e) Elbow angle (Choobineh et al., 2004d).

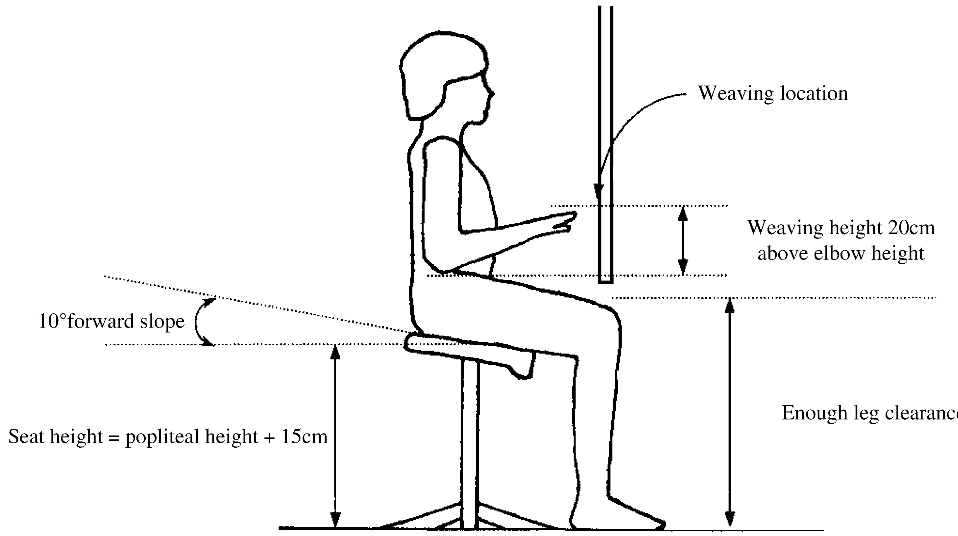

Fig. 4. Guidelines for adjustment of a hand-weaving workstation (Choobineh et al., 2004d).

The results on perceived posture showed that lower weaving heights (+10 and +20 cm) resulted in more favored posture in neck, shoulders and elbows. In some cases, favor inclined towards weaving height +20 cm. Regarding seat type, conventional and high seat with forward slope resulted in more favored posture in back and knees. Additionally, the results indicated that weaving height +30 cm caused more postural discomfort as compared to weaving heights +10 and +20 cm. Weaving height +20 cm generally caused less postural discomfort. Based on the results, a high seat with forward slope provided a good work set-up leading to less back discomfort.

Based on the test subjects' judgments, the best weaving height was +20 cm. The results revealed that when weaving height was adjusted at +20 cm, the test subjects perceived the overall condition better than their own workstation in industry. The results of statistical analyses on the subjective variables were basically in agreement with those of quantitative postural variables.

On the basis of the findings and with regards to the workstation parameters studied in this experiment, the following guidelines were developed for adjustment of carpet hand-weaving workstation:

(a) The weaving height should be adjusted at 20 cm above elbow height.
(b) The 10° forward-sloping high seat should be used in hand weaving workstation.

The guidelines are visualized in Fig. 4.

4. Discussion

In developing countries, the scale of use of human resources in small-scale industries is enormous and it is a labor-intensive sector. In this situation, it is obvious that very small improvements in working conditions, implements, tool design or working methods can lead to large benefits (Sen, 1984). It is believed that the occupational health programs in developing countries should focus more on the informal sector where a large portion of workers are employed (Kromhout, 1999). Unfortunately, the traditional approach to occupational health has tended to concentrate mostly on factory and mine workers in urban industrial settings and has neglected the occupationally related health problems in the informal or unregulated sector where the majority of many developing countries' population lives and works (Christiani et al., 1990). This is so in spite of the fact that this sector is more vulnerable for musculoskeletal injuries, accidents and poisoning (Glass, 1998). This traditional approach should be changed as experience and evidence have proved the importance of small-scale industries in diverse socio-economical aspects and sustainable development (Chen et al., 1999; Frijns and Vliet, 1999).

In Iran, the hand-woven carpet industry is an informal small-scale industry and employs a large number of the national work force. Like other informal small-scale industries around the world, this industry also faces occupational health problems and weavers have been an ignored population from this viewpoint. Most health problems in this sector are originated from ergonomics risk factors (Choobineh et al., 2004a). Any improvement program in this industry should, therefore, focus on ergonomics aspects of hand weaving operation. In the following, the findings of the two phases of the present study are discussed.

4.1. Phase I

The questionnaire showed that symptoms from the musculoskeletal system were common among weavers. Comparison of the results of this study with the results of

Table 3
Comparison of the point prevalence of musculoskeletal symptoms in neck and back in the general Iranian population and the weavers studied (Choobineh et al., 2004c)

Body region	Study population (age = 15–69)	General Iranian population (age = 15–69)	P[a]
Neck	22.8%	10.2%	<0.001
Upper and lower back	34.64%	25.29%	<0.001

[a]Test of proportion.

National Health Survey of Iran (National Research Center of Medical Sciences of Iran, 2001) revealed that the differences between the prevalence of musculoskeletal problems in neck and back regions were significant (Table 3). This indicated that carpet weaving could be generally considered a high-risk occupation for developing MSDs (Choobineh et al., 2004c).

It was shown that during the last 12 months there were in total 15 368 days of sick leave due to musculoskeletal problems. Accordingly, the average sick leave for each weaver was 10.68 days/year (SD = 31.3 days). Generalizing this feature to the weavers' population of Iran (2.2 millions) yielded 23 496 000 of lost working days during the past 12 months. This estimation indicated that, regardless of indirect costs and negative effects of musculoskeletal problems on product quality, neglecting ergonomics considerations in this small-scale industry caused pronounced direct costs in the form of lost working days.

The majority of ergonomics shortcomings and important factors for musculoskeletal symptoms in weaving operation originated from ill-designed weaving workstation. It could, therefore, be concluded that any working conditions improvement program in this industry had to focus on designing ergonomics-oriented weaving workstation (Choobineh et al., 2004c).

The weaving workstation, which was designed based on the developed general guidelines in the first phase of the study, was acceptable to the weavers and contributed to improved working posture. The results of the preliminary prototype test demonstrated that the new design improved working conditions noticeably (Choobineh et al., 2003; Choobineh et al., 2004c).

Given the cross-sectional design of this phase of study and the collection of symptoms data by self-report, these findings must be interpreted with caution. Self-report may reflect denial, deception, or difficulty in recall. Finally, since the analysis was limited to currently working weavers, weavers who had left the job due to musculoskeletal problems may have been excluded from the study. Thus, the data may underestimate reported symptoms.

4.2. Phase II

In the second phase of the comprehensive study, it was shown that in weaving operation the determinant factor for head, neck and shoulders postures was the weaving height. Trunk and elbows postures were shown to be dependant on both design parameters investigated. The results indicated that the determinant factor for weavers' perception on neck, shoulders and elbows was the weaving height, and on back and knees was the seat type. Based on the results, two guidelines were presented to improve working posture: (a) the weaving height should be adjusted at 20 cm above elbow height; (b) the 10° forward-sloping high seat should be used at the weaving workstation. In the recommended workstation, working posture is appropriate and perceived postural discomfort is reduced.

5. Conclusion

The comprehensive study showed that poor working conditions and musculoskeletal problems in Iranian hand-woven carpet industry occurred in high rate. Thus, improvement of working conditions and control of MSDs risk factors seemed essential. Since the majority of ergonomics factors for developing musculoskeletal symptoms among weavers were attributable to poor-designed weaving workstation, it was concluded that any ergonomics interventional program had to concentrate on designing ergonomics-oriented weaving workstation. By combining the results of the two phases of the comprehensive study, guidelines for ergonomics weaving workstation design were presented. In this workstation, loom is vertical. Seat, loom and weaving heights are adjustable. There is enough leg room under the loom. The seat with 10° forward slope is adjusted 15 cm above the popliteal height of the weaver and weaving height is set at 20 cm above the elbow height. It is believed that the recommended workstation improves working posture and results in reduced postural stress on weavers' bodies and, consequently, reduced prevalence of MSDs symptoms.

In this study, no attempt was made to measure the effects of the developed weaving workstation on weavers' performance. Further field trials will be needed to test efficiency under real production conditions.

Finally, in IDCs, great efforts are directed towards encouraging the development of small-scale industries as the engine for growth of their economics (Reverente, 1992). If the carpet industry is supposed to work as a powerful engine to bring positive economic outcomes for the country, it should receive appropriate attention from different viewpoints, above all ergonomics. Given this, as the Iranian carpet industry like other informal small-scale industries around the world faces serious problems such as lack of registration, lack of legislative support, geographical widespread, large number, exclusion from health and safety acts and regulations, low capital resources and income, and finally low priority in the health service planning, it seems that any interventional program for improving working conditions needs the government involvement, and should be planned, sponsored and implemented by the governmental organizations responsible for the occupational health and safety affairs in the country.

Acknowledgements

Research funding for this study was provided by Institute of Public Health Research, Tehran University of Medical Sciences, via project no. 241/81/38.

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