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ORIGINAL ARTICLE

Evaluation of Compressive and Shear Forces Exerted on the Lower Back in Manual Load Handling Tasks among Young Workers of Selected Block Maker Using 3DSSPP

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ABSTRACT

Due to the negative influence of manual load handling on the lower back, it leads to low back disorders and high mechanical loads. The present study was aimed to investigate forces exerted on the lower back during manual handling in young workers in selected block-making workshops. This descriptive, cross-sectional study was carried out on 40 young workers with an average age of 31 years old in several block-making industries in 2020. 3DSSPP Software was used for biomechanical analysis of the forces exerted on the lower back. The prevalence of musculoskeletal disorders was assessed using the Standard Cornell Questionnaires. Spearman, Friedman, and ANOVA correlation tests via SPSS software version19 were used to determine the relationship between demographic variables, the prevalence of musculoskeletal disorders, the relationship between the prevalence of musculoskeletal disorders, the amount of compressive, and shear forces on workers' backs. The results showed that the mean compressive and shear forces exerted to the lumbosacral joint (L5/S1) were 3194.85 ± 1064.326 and 473.17 ± 89.451 N, the intervertebral disc (L4/L5) were 3924.78 ±4344.87 and 383.18 ± 154.554. The findings also indicated that the highest prevalence of pain was related to the lower back 45% and right knee 30%. There was a significant relationship between the mean score of musculoskeletal disorders obtained from the Cornell questionnaire with age, work experience, and weight and body mass (0.001> P). The shear forces exerted to the lower back were higher than the permissible levels by 30% to 37% of respondents, and on average 42.5% of them experienced compressive forces. Thus, it can cause a lot of injuries to the back if lasts for a long time. The results showed that manual load handling was dangerous for this group's ages. Consequently, people may suffer serious injuries and disorders particularly lower back disorders.

KEYWORDS: *Manual Load Handling, Cornell Questionnaire (CMDQ), Low Back Pain, 3DSSPP Software, Block Maker Industries, Compressive Force, Shear Forces*

INTRODUCTION

The American National Institute of Occupational Safety and Health defines musculoskeletal disorders as a group of conditions that involve nerves, tendons, muscles, and supporting structures such as the intervertebral discs. They determined a wide range of disorders that vary in severity and range from mild periodic symptoms to chronic and debilitating conditions[1].

The results of previous studies proved that more than half of absenteeism in workplaces is due to musculoskeletal disorders. Based on the International Labor Organization report, about 160 million work-related illnesses occur each year around the world, which is the highest number recorded that is associated with MSDs (Musculoskeletal Disorder)[2]. Regardless of technology improvement in production process during past decades, a majority of workforces' tasks depend on manual transportation of cargo, either accidentally or professionally [3]. These can be classified into lifting, lowering, pushing, pulling, and carrying objects via hand's muscles forces which ultimately leads to fatigue and work-related musculoskeletal disorders [4]. One of the most common occupational musculoskeletal disorders caused by manual load-bearing activities, mainly lifting weights, is lumbar injuries [5].

Thus, the Low Back Pain (LBP) identified as the main cause of disability and working days lost compared to other musculoskeletal disorders [6]. A systematic review showed that lifetime prevalence ranged from 11% to 84% in developed countries and 14% to 72% in Africa [7, 8]. European and developed countries reported a prevalence of 17.8% and 28.8% representing the impact of LBP among young people [9, 10]. However, studies carried out in 29.1% of African adults revealed that LBP is a frequent complaint and an important public health issue [7]. The epidemiology of LBP in young ages of developing countries has important implications which could result in severe and chronic morbidity in adulthood. Hence, a great share of public health system expenses related to LDB disorders treatment [7]. However, information about Iranian young workers' health condition is not sufficient.

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Workforce age is one of the affecting factors in the study of harmful factors. So, in order to reduce the probability of low back pain among 50-60 years old workers, manual handling tasks are handled by a younger workforce most of the time. However, due to the lack of experience among the young workforce, an increase in LBP can be seen among them [11, 12].

One of the industries that ergonomically causes musculoskeletal disorders is the block-making industry. Manual handling of blocks, improper posture of the worker, continuous bending and rotation, multiple repetitions of manual handling of loads, and long-standing are the biomechanical factors of this industry [13]. These postures imposes a lot of force on the lumbar spine, with a heavier load on the fibrous layers of the discs [14]. In order to control the incidence of musculoskeletal diseases and low back pain and to improve workforce health condition, intervention programs can be developed by evaluating musculoskeletal disorders in workplace, in addition to identifying risk factors and the level of exposure of young workers to them.

All these concerns should be addressed, particularly among Iranian female workforce groups to get a comprehensive view about the agronomical condition in young workers community. On top of that, a proper screening method can be defined to measure the force exerted on the lumbar region in manual cargo handling tasks in the industry. Therefore, this study was aimed to analyze the prevalence of LBP and the associated factors among young workers engaged in the selected block-making workshops.

METHODS

This descriptive, cross-sectional study was conducted in the selected block-making workshops in 2020. The respondents of this study was selected among male workers in the selected block-making workshops on three provinces (East Azerbaijan, West Azerbaijan, North Khorasan). In the current study, the sample size according to the results of previous studies in this field was obtained using the following formula to estimate the mean:

$$N=\frac{Z_{1-\alpha/2}{}^{2}\times\sigma^{2}}{d^{2}}$$

The level of significance was equal to 95% of confidence ($Z_{1\text{-a}/2}$ = 1.96), N as the standard deviation was 300 (d), and the average compressive force on the waist (σ) based on similar studies [15-17], 900 N. Based on the calculations, 40 respondents were selected to increase the accuracy of the study o as a multi-stage cluster. In the current study, the respondents were 25 to 40 years old and one year of work experience as a minimum experience was included. However, those who did not want to participate in the current study, having non-occupational diseases, having affective accident history, and congenital disorders of the musculoskeletal system were excluded.

Risk of musculoskeletal disorders:

Three-Dimensional Static Strength Prediction Program (3DSSPP version 6.0.6) was used to assess the risk of musculoskeletal disorders, biomechanical analysis of compressive, and shear forces exerted to the lower back in manual load handling activities, including manual load lifting and lowering.

This software is known as one of the powerful tools in analyzing slow movements in manual load handling tasks, assessing risk factors such as improper posture, analyzing body imbalance when lifting load, body rotation and forces exerted on the whole body or back [18]. This software is a quantitative indicator for biomechanical analysis of lifting and lowering activity. It also provide a static biomechanical model based on body posture to determine compresses and shear forces exerted to the lumbosacral joint (L5/S1) and the intervertebral disc (L4/L5). Thus, it is widely used to calculate the weight of the load and anthropometric dimensions [19].

Firstly, to analyze the posture of employees, biometric data were entered into software including sex, weight, and height of the worker in the anthropometric section, and the weight of the load that the worker lifts with both hands (see Table 1). Secondly, to obtain information related to each posture, a photo was taken from two front and profile dimensions and entered into the relevant program window. Thirdly, manual load handling postures data were used to estimate the connection angles of different joints of the body in the posture taken for manual load handling. Finally, we used these pictures to determine the position of the load relative to the worker's body and to stimulate the person's posture in the software. An example of the closely simulated posture has been presented in Figure 1. This software is able to provide analysis based on the worker’s posture simulating. Therefore, we could determine a three-dimensional analysis of the lumbar posture to the amount of compressive force on the L4/L5 intervertebral disc, and the lumbar posture in the sagittal axis. Consequently, the amount of compressive force on L5/S1, the tensile or compressive force of the ligament, the risk of lumbar injuries, and the shear force on L5/S1 were determined based on the obtained values. Figure 3 shows an example of the output of lifting in a block-making workshop by workers in this software.

According to the National Institute for Occupational Safety and Health (NIOSH) recommendations [20], a compressive force of less or equal to 3400 N indicates a low risk of back injury. However, the results of previous studies in this field suggested that 3400-6400 N is a moderate risk of back injury, and a value higher than 6400 N indicates a high risk. A shear force less than or equal to 500 N indicates a low risk of back injury whereas a shear force higher than 500 N indicates a high risk of back injury [19].

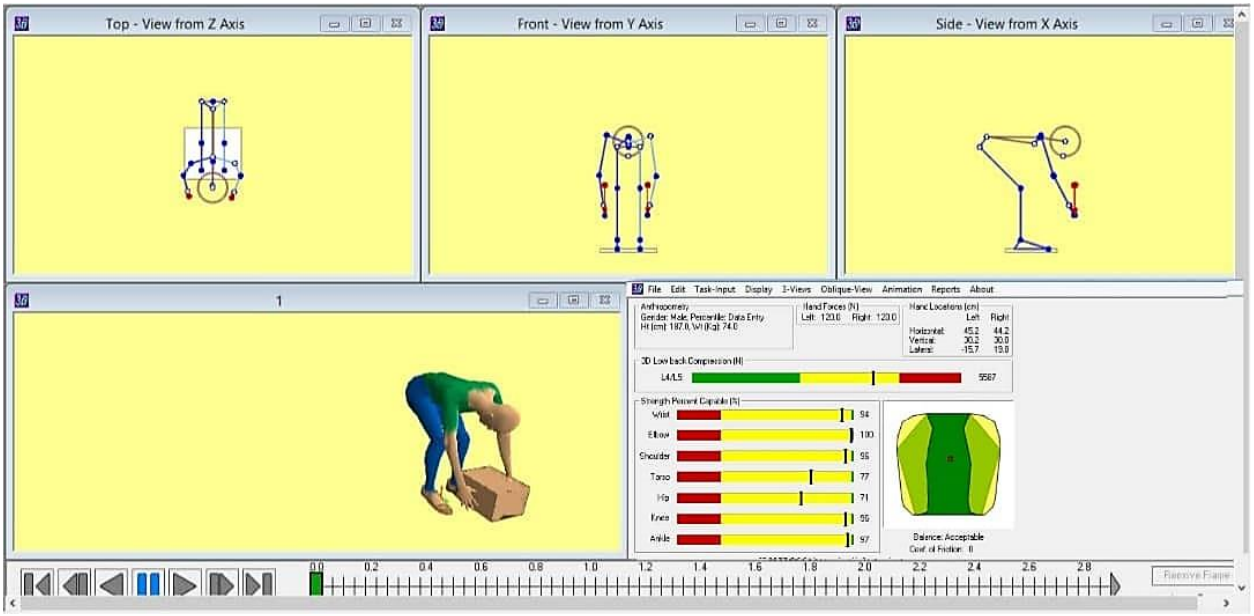

Fig 1. The interface of 3DSSPP Simulation

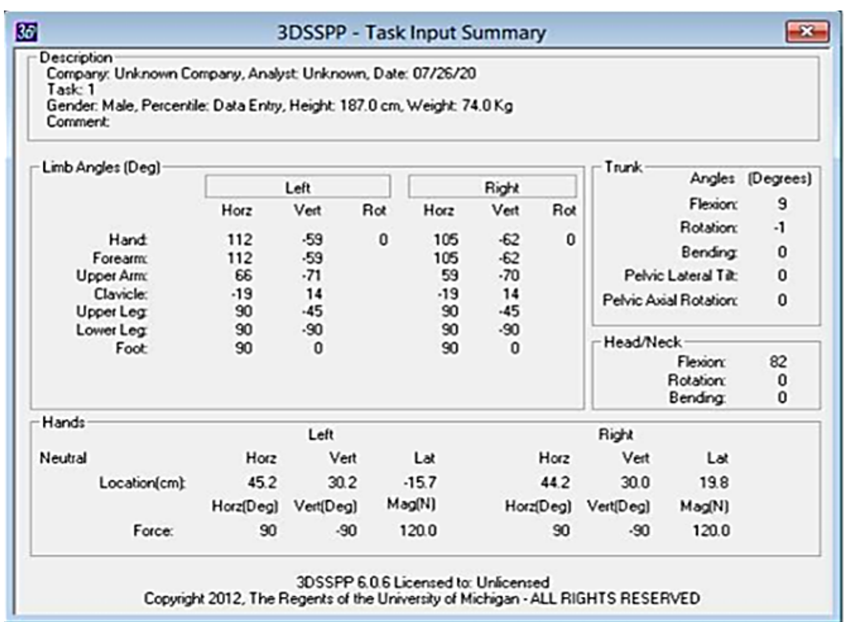

Fig 2. Limb Angle Input in 3DSSPP software

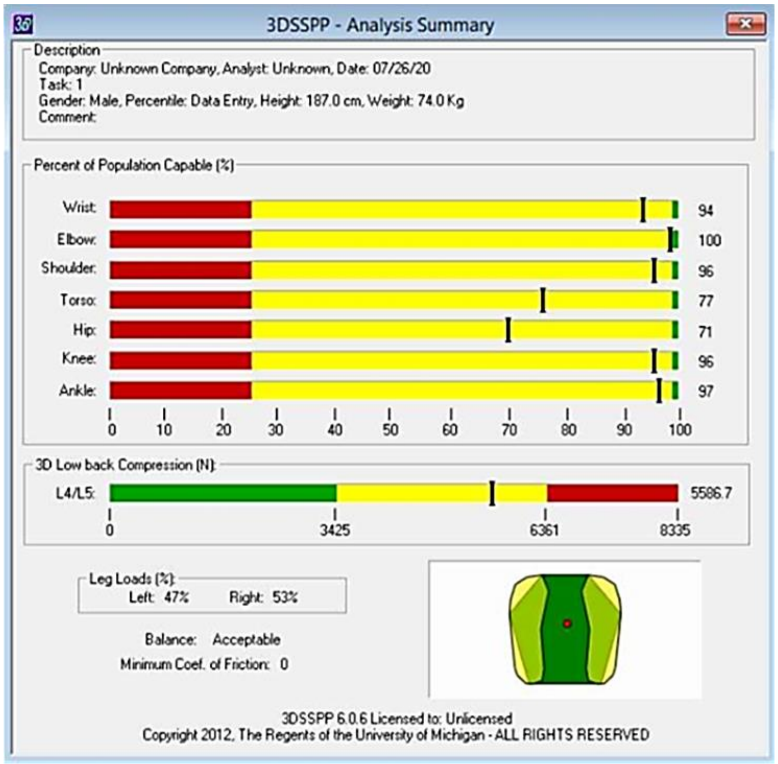

Fig 3. Output Summary in 3DSSPP

Prevalence of musculoskeletal disorders:

The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ, male version) was used to assess the prevalence of musculoskeletal disorders. The validity and reliability of this questionnaire have been confirmed in the study of Abedi et al., and Kashani et al., as Cronbach's alpha for this questionnaire is 0.98 [16, 21].

The Standard Cornell Questionnaire (CMDQ) is an effective self-reporting tool in assessing the extent of musculoskeletal discomfort that provides information about the presence and severity of pain and discomfort in 12 parts of the body including neck, left and right shoulders, upper back, right and left upper arm, lower back, right and left forearm, right and left wrists, hip, right and left upper legs, right and left knees, right and left lower legs, right and left feet. The score obtained for each organ will be between 0 and 90, which is multiplied by the repetition score (never = 0, 1 to 2 times a week = 1.5, 3 to 4 times a week = 3.5, daily = 5 and several times On day = 10), the score of discomfort (2, 3 and 1) and the score of interference with work (2, 3 and 1). In calculating the questionnaire, zero is placed instead of the embedded data. This questionnaire was designed and implemented by Allen Hedge.

Statistical Analysis:

The related study data were analyzed using SPSS software version 19. Descriptive statistics were used to report the degree of the risk factor for work posture, and the frequency of musculoskeletal disorders. Moreover, a multiple regression test was conducted to investigate the relationship between the incidence of musculoskeletal disorders and the final score obtained from 3DSSPP software with the studied demographic variables. Pearson correlation coefficient test was used to determine the relationship between musculoskeletal disorders of the kernel and the final score of the rapid stress assessment method. In all tests, a 95% confidence level was considered.

Figure 4 shows the flowchart of the implementation steps of the study.

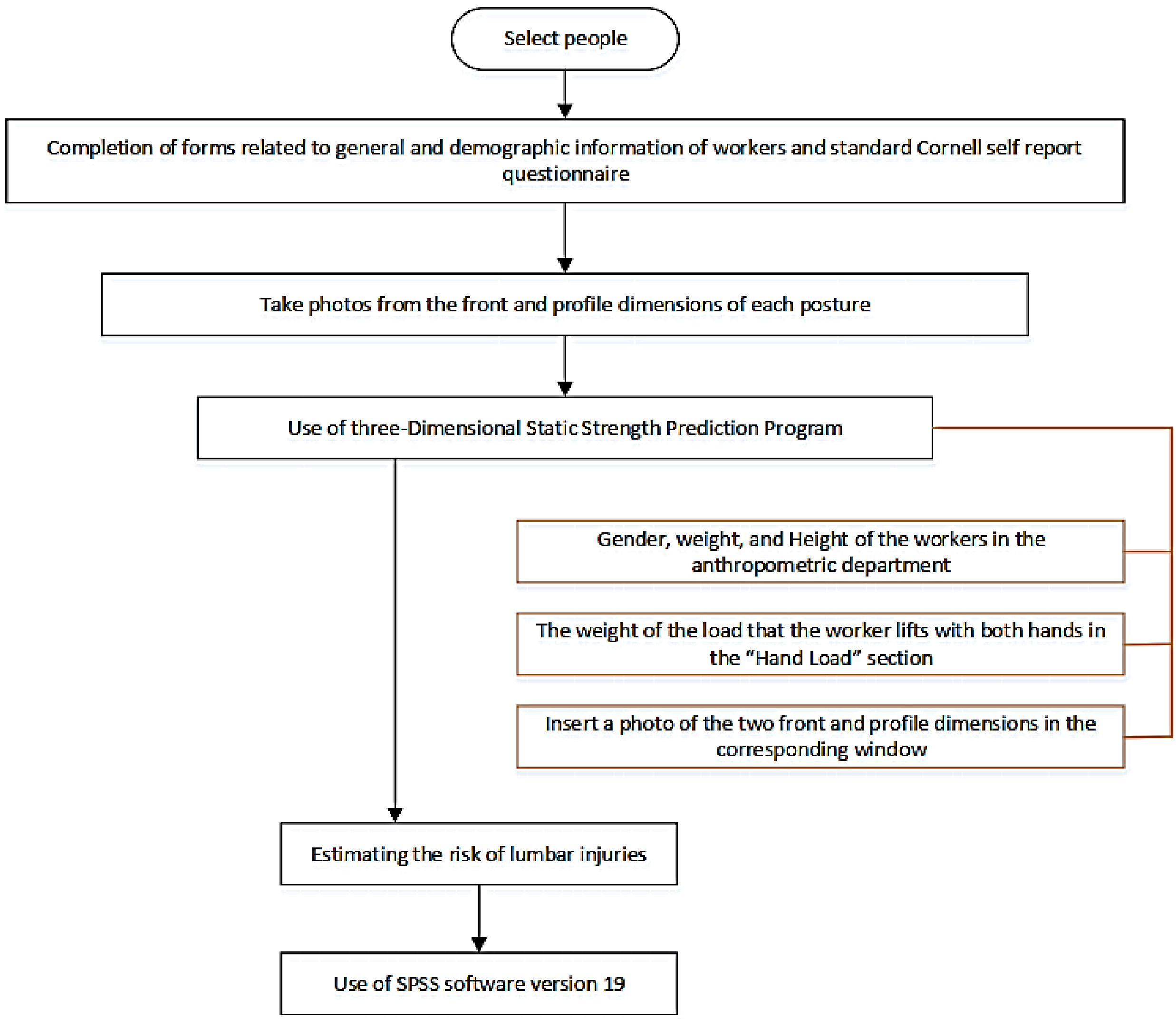

Fig 4. Flowchart of study implementation steps

Results

In the present study, 31.22± 5.15 years old workers were included. The mean weight and height were 85.2 kg and 178 cm, respectively. The mean body mass index (BMI) was 26.88. The subjects had an average of 5.45 years of work experience. The demographic information of the participants has been presented in Table 2.

The results of the Cornell questionnaire showed that the musculoskeletal disorders of the right forearm and the left foot had the highest incidence of several times a day (12.5%). Also, musculoskeletal disorders in the lower back were 45% and the right knee was 30% representing the highest incidence three or four times during a week (Figure 5).

Table 2. Demographic information of study participants

Parameters	Minimum	Maximum	Mean	Standard deviation
Age (years)	25	40	30.875	4.6654
Work Experience (years)	1	15	5.48	3.4582
Weight (kg)	65	130	85.280	13.6351
Height (cm)	168	178	178.080	5.0828
BMI	18.79	42.45	26.8871	4.15733

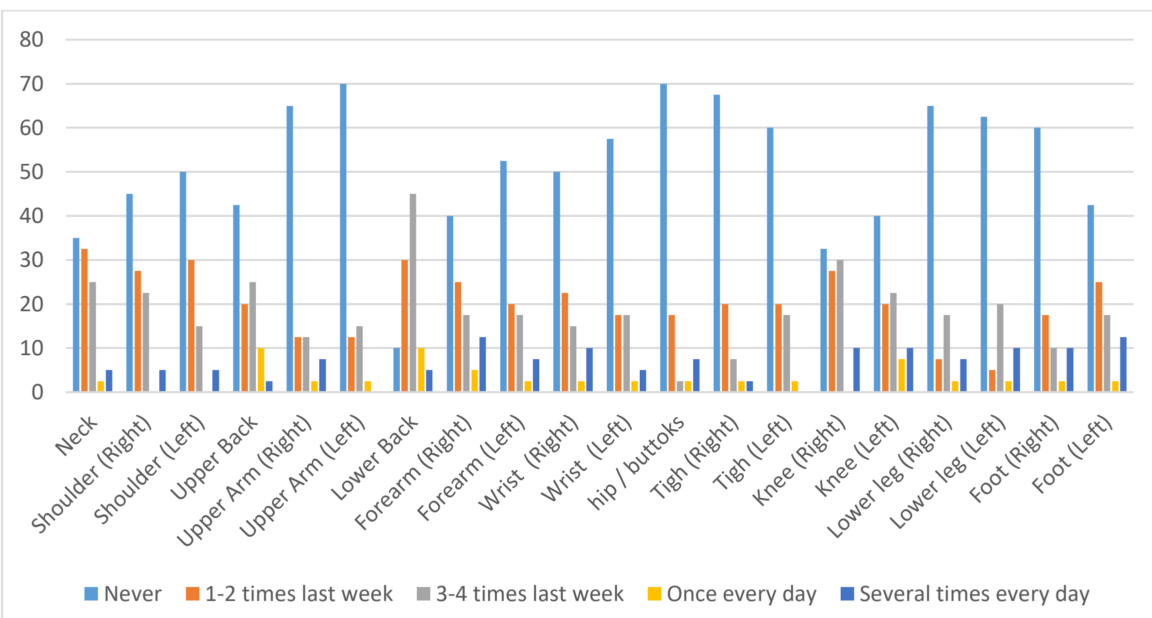

Fig 5. Percentage of the severity of musculoskeletal disorders in workers according to the Cornell questionnaire in terms of 20 areas of the body

The results showed that pain in the lower back, left knee, and right foot had the highest impact on LBP 32.5%, 22.5%, and 20%, respectively. For moderate pain, the lower back, neck, and left shoulder were affected with 45%, 35%, and 35% (see Figure 6).

According to the results of the Cornell questionnaire, musculoskeletal disorders in different areas of the body were determined in the lower back and left and right feet and the left knee seen with 35%, 25%, 25%, and 25%, respectively (Figure 7).

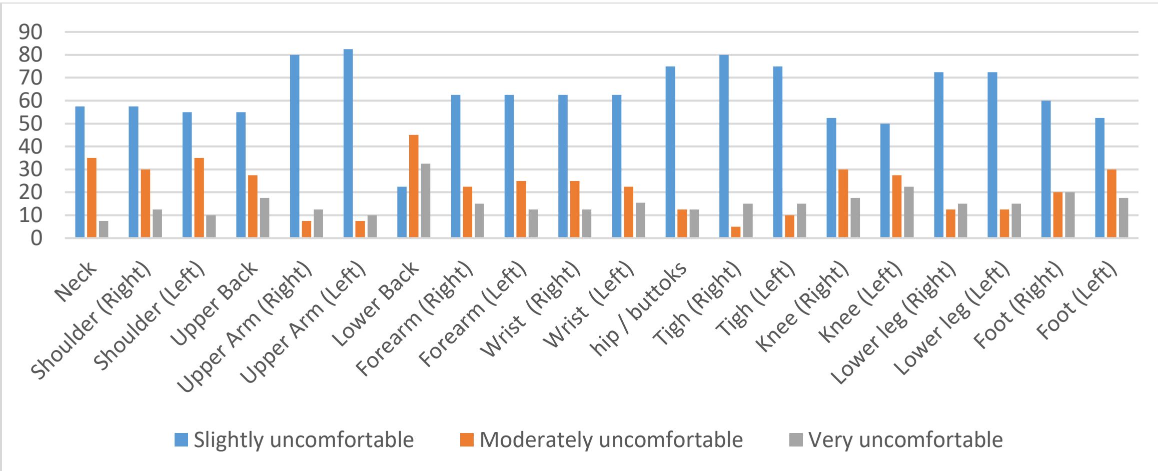

Fig 6. Musculoskeletal disorders impact on pain sensation of workers according to the Cornell questionnaire in terms of 20 areas of the body.

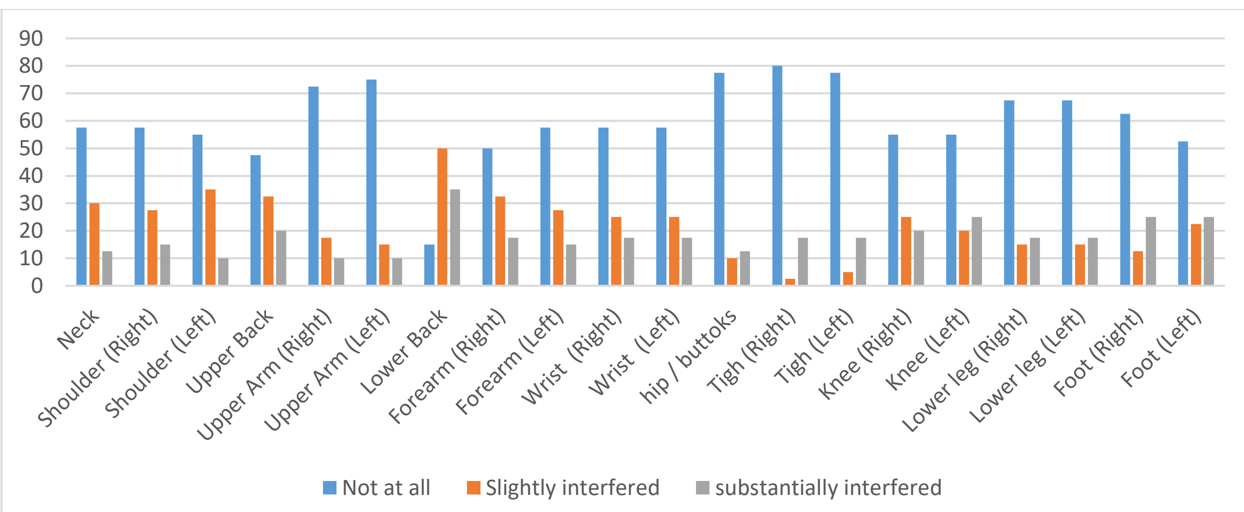

Fig 7. Musculoskeletal disorders impact on different parts of the body on workers' ability to work according to the Cornell questionnaire in terms of 20 areas of the body

The outcomes of analysis using 3DSSPP software showed that the mean compression and shearing forces applied to the lumbosacral joint (L5/S1) were 3194.85 ± 1064.326 and 473.17 ± 89.451. The shearing forces on the intervertebral disc (L4/L5) were 3924.78 ± 4344.879 and 383.18 ± 154.554 N, respectively (Table 3).

The number of compression forces on L4/L5 joint in 55% of workers was in low-risk conditions. It means that exerted force was well below 3400 N. However, 42.5% were categorized in medium risk and 2.5% were in high risk. In the case of shear forces, 70% of workers were in low-risk conditions, i.e. less than 500 N (Table 4).

Table 3. Descriptive statistics of compression and shearing forces on waist (N = 40)

Forces on the waist	Minimum (N)	Maximum (N)	Mean (N)	Standard deviation
Compression forces on L5/S1	417	5730	3194.85	1064.326
Compression forces on L4/L5	879	30017	3924.78	4344.879
Shearing forces on L5/S1	306	650	473.17	89.451
Shearing forces on L4/L5	54	660	383.18	154.554

Table 4. Frequency distribution of compression and shearing forces on the L4/L5 joint

Frequency distribution of compression force on L4/L5 joint			
Amount of force (N)	Risk classification	Number of workers	Percentage of workers
---≤ 3400	Low risk	22	55
3400 < --- ≤ 6400	Medium risk	17	42.5
6400 < ---	High risk	1	2.5
Frequency distribution of Shearing force on L4/L5 joint			
Amount of force (N)	Risk classification	Number of workers	Percentage of workers
---≤ 500	Low risk	28	70
--- > 500	High risk	12	30

The estimated amount of compression forces on L5/S1 intervertebral disc was equal to 57.5%. It means that workers were exposed to forces of less than 3400 N and 42.5% were exposed to forces of 3400 to 6400 N.

In terms of the frequency distribution of shear forces on L5/S1 intervertebral disc, 62.5% of workers were exposed to low risk of these forces, and 37.5% were exposed to high risk (Table 5).

Table 5. Frequency distribution of compression and shearing forces on L5/S1 intervertebral disc

Amount of force (N)	Risk classification	Number of workers	Percentage of workers
Frequency distribution of compression force on L5/S1 intervertebral disc			
Amount of force (N)	Risk classification	Number of workers	Percentage of workers
---≤ 3400	Low risk	23	57.5
3400 < --- ≤ 6400	Medium risk	17	42.5
6400 < ---	High risk	0	0
Frequency distribution of Shearing force on L5/S1 intervertebral disc			
Amount of force (N)	Risk classification	Number of workers	Percentage of workers
---≤ 500	Low risk	25	62.5
--- > 500	High risk	15	37.5

Analytical analysis of the data using the Friedman test showed that there was a direct relationship among the mean score of musculoskeletal disorders obtained from the Cornell questionnaire in neck, shoulder, upper and lower back, upper arm, forearm, wrist, buttocks, thighs, knees, lower legs, feet with age, work experience, weight of individuals, and repeated measures analysis of variance (ANOVA) with height and body mass index (P< 0.001) (Table 6).

More so, results of two applied tests showed that there was a significant direct relationship between compressive and shear forces on L5/S1 lumbosacral joint, L4/L5 intervertebral disc, and the prevalence of musculoskeletal disorders (P <0.001) (Table 7).

Table 6. Relationship between demographic variables and the prevalence of musculoskeletal disorders

Variable	P-value	Statistical Test
Age	P< 0.001	Friedman Test
Work Experience	P< 0.001	Friedman Test
Weight	P< 0.001	Friedman Test
Height	P< 0.001	Repeated Measure ANOVA
BMI	P< 0.001	Repeated Measure ANOVA

Table 7. Relationship between compression and shearing forces on L4/L5 lumbosacral joint and L5/S1 intervertebral disc with the prevalence of musculoskeletal disorders

Variable	P-value	Statistical Test
Compression forces on L5/S1	P< 0.001	Repeated Measure ANOVA
Shearing forces on L5/S1	P< 0.001	Repeated Measure ANOVA
Compression forces on L4/L5	P< 0.001	Friedman Test
Shearing forces on L4/L5	P< 0.001	Repeated Measure ANOVA

According to the Spearman test, there was a negative correlation between the compression forces on L4/L5 intervertebral disc and the mean score of the upper back obtained from the Cornell questionnaire (P = 0.02). However, there was a positive correlation between the shearing forces on the L5/S1 lumbosacral joint with body mass index (P = 0.008) and weight (P< 0.001).

There was a negative correlation between the compression forces on L4/L5 intervertebral disc and the mean score of the knee (P = 0.033), right lower leg (p = 0.037) obtained from the Cornell questionnaire, and the shearing forces on the L5/S1 lumbosacral joint with the mean score of the right lower leg (P = 0.038), thigh (P = 0.034) and Right Foot (P = 0.021). Also, according to the same test, there was a significant negative correlation between work experience and shear forces on the L4/L5 intervertebral disc (P = 0.03) (Table 8).

Table 8. Some correlations examined using the Spearman test

The first variable	The second variable	Correlation Coefficient	P-value
Compression forces on L4/L5	the mean score of the upper back	- 0.367	0.020
Shearing forces on L5/S1	BMI	0.412	0.008
Shearing forces on L5/S1	Weight	0.580	< 0.001
Compression forces on L4/L5	the mean score of the right knee	- 0.339	0.033
Compression forces on L4/L5	the mean score of the right lower leg	- 0.332	0.037
Shearing forces on L5/S1	the mean score of the right lower leg	- 0.330	0.038
Shearing forces on L5/S1	the mean score of the right thigh	- 0.335	0.034
Shearing forces on L5/S1	the mean score of the Right Foot	- 0.363	0.021
Shearing forces on L4/L5	work experience	- 0.334	0.03

DISCUSSION

The Low back pain (LBP) is the main cause of people's disability and absence from work. The block-making industry causes serious musculoskeletal disorders due to frequent load handling, improper posture, and prolonged standing. The present study was aimed to investigate forces exerted on the lower back during manual handling among young workers in the selected block-making workshops.

In the current study, the highest discomfort was in the lower back (32.5%), left knee (22.5%), right sole (20%), neck, and shoulders. These results were consistent with the results of the study of Dormohammadi et al. (2011) on tile industry workers on the prevalence of musculoskeletal disorders in knee, leg, back, and waist [22]. Similarly, in the study of Deepin Das et al., annual prevalence of musculoskeletal disorders in the lower back was reported by the majority (86.8%) of handcraft workers [23].

The results study conducted by Eskandari et al., showed that lumbar region injury was high in manual load handling tasks [24]. The force exerted on the waist among construction workers was in line with the results of the present study [13]. In the study of Choobineh et al., the highest prevalence of musculoskeletal disorders was in lower back, knees, and upper back [25]. In this study, 42.5% of people had experienced a compressive force between 3400 and 6400 N which is moderate risk level in L5/S1. It may be due to the unfavorable posture or lifting height. In this regard, the study of Mir Mohammadi et al. among food industry's workers attributed to the amount of compressive force on the waist to the weight of the load, unfavorable posture, and anthropometric dimensions of individuals [17]. A study by Gallagher et al. (2015) showed that lifting 11.3 kg load packages increased the compressive force on the waist to above 3400 N, which is more dangerous if the load is increased to 23-45 kg [26]. In this study, which carried blocks of 12-15 kg, about 45% of people felt a compressive force higher than 3400 N. In some cases, block-making workers had to lift two blocks at the same time, which could increase the compressive force.

The degree of discomfort and pain in neck, shoulders, upper and lower back was related to age.Kudo et al., proved that the risk of lumbar spinal cord injury was higher in older people than in younger people [27].

Salehi et al. Showed that by changing the height and weight of the load, the amount of force on L5/S1 nuts has changed, which was consistent with the results of this study [15]. Mazloumi et al., investigated the impact of anthropometric dimensions change, the horizontal distance of the load to the body, and the load height reduction. Results showed that these changes may increase force on L5/S1 disk [28]. On the other hand, the shear force on L5/S1 nut for 37% of people was above 500 N, which shows a high-risk level and is related to the BMI of people. Furthermore, it was found that the compressive and shear force was related to the BMI of individuals [28]. In a study by Gallagher et al., whenever pallet was next to the conveyor the shear force on the lower levels of the pallet was 800 N, which causes the forward bend to the peak [26]. In this study, about 12 people felt a shear force higher than 500 N. This can be caused by excessive bending or rotation of the back when lifting a load.

The results of 3DSSPP software indicated that the compressive and shear forces on the joints in some cases exceed the 34 limits of NIOSH and were directly related to the prevalence of disorders in low back pain. This result was consistent with the study of Salehi et al., which was performed by the HCBCF method [15]. However, Asadi et al., in their study showed that the prevalence of low back pain was not related to compressive and shear forces [3]. It also contradicts the results of the study of Mir Mohammadi et al [17]. One of the reasons for this discrepancy could be the lack of rotation of work and having routine tasks in the present study. In the article by Faqih et al., Musculoskeletal disorders can be due to repetitive tasks, inappropriate posture, and the nature of the work [29]. In this study, workers used a variety of building blocks. A study by Hess et al. (2010) examined the impact of two types of concrete structures on masons. Results showed that even if some blocks were lighter, a variety of structures can put pressure on the lumbar region and be dangerous [30].

This method provide better results in measuring the exerted forces based on the important parameters in the manual lifting of the load. However, it should be noted that this method does not take into account factors such as the frequency of lifting the load.

CONCLUSION

The values of the forces measured via 3D SSPP software showed that the shear forces for 30 to 37% of people were above the permitted limit, and the compressive forces for 42.5% of people were on the average level. In the long run, these amounts can cause a lot of damage to the lumbar vertebrae. The results showed that carrying loads was dangerous for young age range. So, older ages workforce will suffer from critical injuries and disorders, especially in the lower back. In order to decrease LBP among workforces, it is recommended to use mechanical lifting equipment, proper training of workers, ergonomic design.

The limitations of this study include changing the posture of workers during photography and also creating problems for workers by the employer while filling out questionnaires.

AUTHORS CONTRIBUTION

The initial idea and design were proposed by the Corresponding author. All authors contributed to data collection, research, writing, and review. All authors, with the final approval of this article, accept responsibility for the accuracy of the content contained therein.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest in the present study

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