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The Adequacy of NIOSH Equation to to Determine the Rate of Stresses Exerted on the Back Based on Compressive Force Estimation

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Abstract

Background: Manual handling may cause workers to deal with various risk factors. Workers performing such tasks repeatedly for a long time are more prone to bodily injuries and physical problems such as back pain.
Objectives: The current study aimed to assess the compressive loads estimation and analysis of forces exerted on the workers' back in manual load lifting tasks using the national institute for occupational safety and health (NIOSH) equation and compare them with the recommended weight limit (RWL).
Methods: It was a cross-sectional study in a laboratory setting on 15 healthy male workers in 2015. The participants were required to randomly perform 25 tasks with four iterations. The lifting index (LI) was calculated by NIOSH equation in simple tasks and compressive loads on the low back (L4/L5) for each task were calculated using the 3DSSPP. Data were analyzed using SPSS version 16.
Results: The results showed that the highest compressive force exerted on the back was equal to 4002 N and the lowest force 1425 N. Moreover, 76% of the tasks were reported to have the highest compressive force greater than the recommended limit; 72% of the tasks had an LI 1 - 3 and 28% of them had an LI less than 1. There was a weak direct correlation between compressive force and RWL.
Conclusions: The NIOSH equation and compressive force estimation function were partially similar to identify high-risk tasks, however, by the compressive force estimation, biomechanical analysis of tasks can be done better since it is quantitative and can determine the exact amount of forces exerted on the back.

Keywords: NIOSH Lifting Equation, Spine Spine Loads, Compressive Force, 3DSSPP, Manual Material Handling

1. Background

Manual material handling (MMH) may expose workers to deal with various risk factors. Workers performing such tasks repeatedly for a long time are more prone to bodily injuries and physical problems such as back pain. The main risk factors or conditions that cause injuries to progress in MMH tasks include poor postures (e.g. bending and twisting), repetitive movements (frequent access, lifting and carrying), applying high force (carrying or lifting heavy loads), pressure points (e.g. gripping loads, leaning on parts or hard surfaces with sharp edges) and static postures (e.g. maintaining a fixed position for a long time) (1). Back pain diseases are the most common musculoskeletal diseases; these diseases rank second in terms of physicians' visits and rank fifth in terms of going to hospitals (2); therefore, the costs associated with them were approximately estimated as $72 billion in the United States in 1997, of which $171 million was related to the costs of back pain in industrial environments. Furthermore, half of all back injuries are caused by manually lifting the load (3-5). MMH is the main cause of damage to the workforce in the United States and four of every five occurred injuries are related to back pain caused by manual material handling (6). There are no official reports on the prevalence of work-related musculoskeletal diseases in Iran and the only official report was based on the reports by the treatment deputy of the social security organization (TDSSO) from 1992 to 1995, which announced musculoskeletal diseases as the cause of 14.4% of total disabilities in the country and also ranked musculoskeletal diseases fourth after the neurological diseases, psychiatric diseases and the cancer among all diseases. Moreover, according to the report by the same deputy in 2001, the highest number of visits to the medical commission for the social security organization (MCSSO) was due to musculoskeletal disorders (7). According to the report by national institute for occupational safety and health (NIOSH), about 60% of compensations arising from physical damages are related to the activity of manual load lifting (8). Statistical findings show that about 50% of back pains are related to lifting, 10% to pushing and pulling, and 6% to load carrying (9). Manual material handling tasks are widely performed in many professions (10). Several studies indicated a relationship between manual load carrying (without the use of auxiliary equipment) and an increased risk of musculoskeletal injuries, especially at the waist and upper extremity (11). Lifting load mechanical equipment such as lifts is effective to eliminate or reduce the injuries to the waist in cases that lifting loads exceed the load bearing capacity of the human. However, loads which humans are capable of handling manually should be moved manually since mechanical equipment carrying speed is much less than that of humans (12). In a study conducted by Arjmand et al. the revised NIOSH equation was used to estimate the forces applied on the vertebral column. For this purpose, 50 lifting tasks were simulated. The obtained results revealed that load lifting tasks in which the trunk forward bending angle is moderate to high (Over 30 degrees), vertebral column compressing forces greater than the recommended limit are created up to 40%. Moreover, the results indicated that it is necessary to consider a multiplier for the trunk forward bending angle (13). Rajaee et al. conducted a comparative study on six quantitative tools (HCBCF, LSBM, 3DSSPP, anybody, simple polynomial and regression) to estimate loads exerted on the spinal cord in 26 static activities. The results of this study showed that 3DSSPP software can be appropriate for symmetrical/asymmetrical tasks with low to moderate forward bending from the waist to perform tasks. In general, the results showed a major difference among tools to estimate the forces on the spinal cord especially compressive forces (14).

Previous studies determined safe limit values for tissues (15). The NIOSH proposed a back compressive force limit of 3,400 N in 1981, indicating that compressive loads less than 3400 N exerted on the back were placed in a safe area and in 1991, in a new edition of the load lifting instruction to reduce the risk of back pain, explained the recommended load amount; therefore, when a user handles a load heavier than the limit, the risk of back pain increases (16).

2. Objectives

Due to the high risk of back pain in manual material handling tasks, The current study aimed to assess the biomechanical estimation and analysis of forces exerted on the back in manual lifting tasks using the NIOSH equation and the University of Michigan's 3D static strength prediction program (3DSSPP).

3. Methods

The current cross-sectional study was conducted from May to June 2015 at the ergonomics laboratory, Ahvaz University of Medical Sciences, Ahvaz, Iran. The participants of the study were randomly selected among male workers who were inexperienced in MMH tasks. The sample size was determined 15 based on the previous studies (17). The exclusion criteria were previous spinal surgery and a significant vertebral deformity resulting from any etiology. After meeting criteria, the study was explained and workers provided informed consent.

3.1. The Study Design

Some boxes weighing 2, 5, 7, 9, 11, 14, 16, 18, 27 and 32 kg with suitable handles with the dimension of 60 × 38 × 31 cm were prepared. An identification code was then assigned to each of the boxes. The source for lifting the load was constant and the destination of the load was a shelf with four floors. The vertical heights of the floors of the shelf were as follows:

First floor: eight centimeters below the shoulder to 30 cm above the shoulder

Second floor: knuckle down to shoulder height

Third floor: leg height to knuckle height

Fourth floor: leg to floor height

Horizontal distances including close (30 cm), medium (60 cm) and spread (80 cm) were marked at the destination toward the middle ankle.

The participants were required to randomly perform 25 tasks with four iterations. An identification code was also assigned to each task.

It should be noted that load weights and the horizontal and vertical distances were determined based on threshold limit values (TLVs) tables provided by the Ministry of Health and Medical Education of Iran. According to the previous study, the boxes with such dimensions are commonly used in the range of jobs available in the community. Moreover, the boxes at Iran's domestic market have the closest dimensions to the ones used in previous studies (17).

3.2. Instrumentation and Method

In the present study to estimate the compressive force, the forward bending angle at the waist was firstly measured online with direct observation using a portable three-axis inclinometer (WILLISTON VT, Inc., USA, MicroStrain. VC-223) made in the United States. The device is fastened around the chest above the sternum and 2.5 cm below the collarbone in a belt containing a small bag. Prior to implementing the device, it was calibrated according to the manufacturer's instruction. The accuracy of the device is reported ± 0.5 degree in various studies, according to the manufacturer statement (18, 19).

To record the trunk reference angle and make each participant's natural trunk angle equal to zero, after placing the device inside the bag, the participants were asked to stand in an upright posture for 30 seconds; therefore, the upper body was fully stretched and upright.

To ensure that no change occurred to the position of the device inside the bag and or to the position of the bag on the body, each participant was again asked after the sampling to stand in a stretched and upright posture for thirty seconds and the final reference angle was also recorded. Then, the compressive force exerted on the back was determined using 3DSSPP.

At the beginning of the task, a lumbar inclinometer was attached to each individual and the participants were randomly asked to perform the tasks and their iterations. The individuals were given 30 seconds to rest after each task. In order to minimize the influence of fatigue caused by load lifting on next tasks, each individual was given a five-minute break after five minutes of activity (performing five tasks). Moreover, no information was disclosed to the individuals regarding weights of loads and forces they exerted when lifting.

Since the information needed to determine the coefficients of load lifting was specific, the recommended weight limit (RWL) was calculated in simple conditions by the NIOSH lifting equation.

3.3. Statistical Analysis Methods of the Results

The greatest exerted compressive force by each individual was accounted for four iterations of each task. Eventually, the data were transferred into the SPSS version 16 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was used to examine the normality of the distribution of data. Pearson correlation test was used to determine the relationship between RWL and the compressive force due to the parametric nature of the data. Moreover, the regression test was used to determine the correlation between the mean compressive forces and lifting index (LI).

Since the data distribution was normal, the T-test was used to compare the compressive forces exerted on the back at the recommended limits.

4. Results

Table 1 shows the demographic characteristics of the participants. The mean age of the participants was 30.13 ± 6.14 years. The mean compressive force exerted on the back at various horizontal and vertical distances from the body are shown in Table 2. Of the 25 performed tasks, the greatest compressive force exerted on the back was related to task 3 equal to 4002 N and the lowest one was related to task 11 equal to 1425 N. According to the greatest compressive forces, it was observed that 19 tasks (76%) had the maximum compressive force higher than the recommended limit (3400 N).

Table 1. Demographic Characteristics of the Study Population

Variable	Mean ± SD	Minimum	Maximum
Age, y	30.13 ± 6.14	23	41
Work experience, y	10.75 ± 4.23	4	18
Height, cm	172.27 ± 9.24	141	179
Weight, kg	74 ± 10.53	61	93

As shown 18 tasks out of 25 (72%) had the lifting index between one and three, and seven tasks (28%) had an LI less than one.

The results obtained from the statistical tests showed that existence of a direct weak correlation between the compressive force obtained from the University of Michigan's program and that of the RWL (correlation coefficient = 0.47, P value = 0.01). Moreover, the results indicated a significant correlation between the compressive force and the lifting index (r = 0.63, P value = 0.001).

5. Discussion

As it can be observed, the mean compressive force in tasks 3 and 12 were higher than those of the standard recommended limit (3400 N). It can be due to the heavier weights of these tasks. Asadi et al. who used the 3DSSPP program to estimate compressive forces exerted on the workers' backs during manual load lifting, concluded that the compressive forces in 17.5% of the subjects were beyond the permissible limit (20). However, the results of the study showed that the mean compressive force was higher than the permissible limit in only 8% of the tasks.

By considering one standard deviation above the mean, the mean compressive force was above the standard recommended limit in nine tasks (36%). This issue is very important and should not be ignored, since the mean compressive force is likely to go beyond the standard recommended limit in the iteration of these tasks by other individuals. The reason in task 4 and 13 seems to be the impact of the external load weight. The increasing trunk forward bending angle and the poor postures can also cause the compressive force to exceed the recommended limits in tasks 16, 18 and 23. Moreover, the simultaneous effects of poor postures and the external load weight on the tasks

Table 2. Estimate Compressive Forces on the Back, the Recommended Weight Limit and Lifting Index

Task	Load, kg	V, cm	H, cm	NIOSH		Compressive Forces			
				LI	RWL	Mean ± SD	Max	Min	Compare With Standard
1	16	175	30	1.48	108	2245 ± 819	4369	1585	S[a]
2	7	175	60	1.29	54	1735 ± 592	3319	1221	S
3	32	95	30	2.13	149	4002 ± 742	6003	3231	(P = 0.003)[b,c]
4	16	95	60	2.13	74	3373 ± 516	4318	2487	S
5	9	95	80	1.6	56	2915 ± 319	3413	2277	S
6	18	70	30	1.07	166	3292 ± 1016	4993	1866	S
7	14	70	60	1.67	83	2750 ± 1096	4500	1669	S
8	7	70	80	1.11	62	2138 ± 983	3730	1263	S
9	14	20	30	0.8	173	2702 ± 1256	4510	1623	S
10	14	175	30	1.44	96	2125 ± 640	3582	1264	S
11	5	175	60	1.033	48	1425 ± 475	2738	980	S
12	27	95	30	2.01	134	3561 ± 621	5057	2606	(P = 0.16)[b]
13	14	95	60	2.08	67	3103 ± 426	4109	2597	S
14	7	95	80	1.39	50	2667 ± 282	3180	2095	S
15	16	70	30	1.07	149	2984 ± 1029	4851	1936	S
16	11	70	60	1.47	74	2485 ± 1044	4128	1529	S
17	5	70	80	0.89	55	1963 ± 906	3367	1101	S
18	9	20	30	0.57	155	2287 ± 1132	4214	1281	S
19	11	175	30	1.13	96	1721 ± 531	3288	1207	S
20	14	95	30	1.04	134	2693 ± 383	3555	2054	S
21	9	95	60	1.34	67	2670 ± 316	3305	2327	S
22	5	95	80	0.99	50	2486 ± 505	3461	1685	S
23	9	70	30	0.6	149	2563 ± 887	3872	1403	S
24	7	70	60	0.93	74	2144 ± 955	3707	1240	S
25	2	70	80	0.35	55	1761 ± 1008	4044	916	S

[a] Means that the mean compressive force is significantly less than the recommended standard.
[b] Means that the mean compressive force is significantly higher than the recommended standard.
[c] The load constant was equal to 23 kg. In addition, the asymmetry multiplier (AM) and the coupling multiplier (CM) were both taken as 1.

6, 7, 9 and 15 can be regarded the reason for the compressive force exceeding the recommended limits. The results of the study by Habibi et al. revealed that musculoskeletal disorders are multifactorial and factors such as trunk bending, load distance from the body while lifting it, and height of load lifting location are among variables that can directly or indirectly create or increase musculoskeletal disorders in people not observing ergonomic principles while working (21). Furthermore, the study by Morshedi et al. showed that by increasing the trunk forward bending to lift loads from the bottom floors, the compressive force exerted on L5/S1 significantly increased compared to that of the upper floors (22). The results of the study by Wu on Chinese females indicated that increasing the trunk angle reduced maximum acceptable weight of lift (MAWL) (23). Several studies suggested that the impact of awkward postures was greater than that of the external load weight in increasing the compressive force (24, 25). As observed, the probable reasons to exceed the recommended limits in seven out of nine tasks with high damaging risk in the current study were considered the awkward postures and the increase in the trunk forward bending angle that confirmed the findings of the previous studies.

The highest compressive force values exerted on the back in the study showed that 19 out of 25 performed tasks (76%) had a compressive force higher than the recommended limit (3400 N). Faber et al. conducted a study on 12 healthy males in Amsterdam, where the participants lifted 10 and 20 kg loads from a height of 29 cm in front of their bodies. They estimated the compressive forces exerted on the participants' backs using kinematic and electromyographic measurements. The maximum compressive forces exerted on the back in these two tasks were 4898 and 5480 N, respectively, which were greater than the recommended limit (26). By comparing the results of the current study with those of Faber, it seems that performing similar tasks can create compressive forces higher than the recommended limits in some individuals, while creating compressive forces below the permissible limit in some others.

Russell et al. compared the results of five load lifting analysis tools, including NIOSH, ACGIH TLV, SNOOK, 3DSSPP, and WA L&I, and stated that it was easier to use the ACGIH TLV, SNOOK and WA L&I methods; however, the NIOSH method had a broader range to determine that a change in which aspect of the load lifting operation can have a greater impact in reducing the force exerted on the back (27). The results obtained by the inclinometer and the NIOSH equation were compared as follows.

The compressive force was higher than the permissible limit in tasks 3 and 12, indicating them as high-risk tasks. However, according to the results obtained from the NIOSH equation, LI was greater than one, which indicated intermediate risk of such tasks. Moreover, tasks 4, 6, 7, 13, 15 and 16, which had high risk of back injury by considering one standard deviation above the mean compressive force, were considered to have moderate risk by the NIOSH equation. Morshedi et al. observed that the compressive force in the performed tasks was greater than that of the standard recommenced limit and the tasks were determined as high-risk ones, while the results obtained by the NIOSH equation indicated the moderate risk of the tasks (22).

Tasks 9, 18 and 23 which exceeded the standard recommended limit by considering one standard deviation above the mean compressive force, were identified as low risk by the NIOSH equation.

Tasks 1, 2, 5, 8, 10, 11, 14, 19, 20 and 21 had a mean compressive force less than that of the standard recommended limit. However, they were identified as the moderate risk tasks by the NIOSH equation. The study by Russell et al. showed that based on the NIOSH load lifting equation, the intended task had a high risk of musculoskeletal disorders occurrence, while estimating the compressive force using the University of Michigan's software identified the same task as low-risk (27).

The results of the comparison between the two methods indicated a significant correlation between the compressive force obtained from the University of Michigan's software and that of the lifting index ($r = 0.63$, P value = 0.001). In the study by Russell et al. a significant difference was observed between the results obtained from the NIOSH load lifting equation and those of the University of Michigan's software that contradicted with the results of the current study (27).

5.1. Conclusions

Based on the correlation obtained between the results of the NIOSH load lifting equation and that of the compression load, it can be concluded that the two mentioned methods had partially similar functions to identify high-risk tasks, however, using the compressive force estimation, biomechanical analysis of tasks can be done better, since it is quantitative and can determine the exact amount of forces exerted on the back.

In the current study, the moment compression force was considered as the evaluating criterion and cumulative compressive force calculations were not carried out; since the number of high risk tasks may increase by calculating the cumulative compressive force for the performed tasks, the cumulative compressive force should be considered for evaluation in future studies.

5.2. Limitation

Due to the large number of assessed tasks and the time-consuming process of review, the sample size was determined 15 participants and more participants can be included in further investigations.

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Footnotes

Authors' Contribution: Davood Afshari: research concept and design, manuscript editing and final approval of article; Samira Kord: literature search, experimental studies, collection and analysis of data and writing the article; Seyed Mahmood Latifi: statistical analysis; Ghasem Mardi: collection of data

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