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Original Article

Assessment of low back disorders risk based on allowable weight limits for manual lifting in Iran

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Abstract: In 2011, load limits for manual lifting were adopted in Iran to protect workers from low back injury without prior testing of accuracy with Iranian workers. This investigation examined how accurate the adopted ACGIH TLVs at the allowable limits predict risk for LBP disorders for a group of Iranian workers using biomechanical criteria. Testing took place in the laboratory with participants completing a series of 2-handed lifting tasks as defined in the Iranian Guideline for Manual Lifting. To test accuracy, both compression and shear forces were estimated for fifteen male Iranian workers who completed 25 lift combinations that varied in height and reach with the maximal allowable load. The findings, when compared to a risk threshold of 3400 N compression and 700 N shear, showed above-threshold forces for compression and little-to-no safety margins with repetitive lifting for most lifts at torso height and below. Since Government, employers and workers use these guidelines to decide on work/workplace design; these guidelines require further review and revision based on the anthropometrics of Iranian people.

Key words: ACGIH TLVs, Anthropometric, Iranian Lifting Guideline, Lifting weight limits, Spinal loads

Introduction

The lifetime prevalence of low back pain (LBP) has been estimated at nearly 70% for industrialized countries[1]. An equivalent measure is not available for developing countries such as Iran, but it is expected to also be high given that manual labor and material handling are known causal factors for LBP disorders[2–6] and industries in developing countries rely on manual labor for material handling and processing. To prevent or mitigate LBP, risk assessment tools have been developed for employers to help guide their decision making on work and workplace design since occupational work factors including lifting, repetitive movements, awkward postures, and forceful action are known causal factors for LBP[7–9]; however, these tools have been developed for industrialized countries. It is unknown whether these tools require modifications before they are used in developing countries.

In Iran, there is both heavy and small industries that employ large numbers of workers to carry out manual labor tasks, and while there is no report on lifetime prevalence of LBP, there is sufficient evidence to show that LBP is a common health concern. Between 1990–1994, LBP was one of the musculoskeletal disorders that made up 14.4% of all disabilities in Iran, and was the fourth most frequent reason for referral to the Medical Commission of

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the Social Security Administration in Iran[10]. Furthermore, both epidemiological and biomechanical studies that have been conducted in Iran have shown that LBP is the most frequent musculoskeletal disorder, and that manual handling and unsuitable workstation conditions are the main reasons for an increased risk of low back injuries[6, 11, 12]. It is clear that government action is required to mitigate the risk of LBP disorders in Iran, particularly as LBP was ranked third among the most costly health issues[12].

A variety of risk assessment tools are available that are based on biomechanical, physiological, psychophysical criteria, or combinations thereof. It is believed that risk assessment tools should be simple to use, yet accurate[13]. The simplest tools only require employers to consider task parameters and not the worker; errors thereby, arise when assumptions regarding the worker are not met. Load limits that are based on biomechanical criteria are subject to error when assumptions on anthropometrics and lift position are not met. This error is systematic when the anthropometrics of a population to which the load limits are applied differ from those of the reference population. Since a large portion of lumbar compressive loads are attributed to awkward trunk positioning[14–17], this error could be substantial and could have serious implications with employers and workers being exposed to a higher risk of injury than is realized, depending on the error.

In 2011, the Environmental and Occupational Health Center within the Iranian Ministry of Health and Medical Education (MHME) adopted the American Conference of Governmental Hygienists (ACGIH) threshold limit values (TLVs) for lifting as allowable load limits for manual lifting[18]. These limits represent work conditions that almost all workers can be exposed to on a daily basis without developing work-related LBP disorders due to exposure to manual lifting tasks[18]. By adopting these limits, Iranian employers are provided with a simple and quick method for assessing risk for work-related LBP for load limits only require assessment of task parameters; moreover, load limits provide clear guidance for employers as to how to lower the risk of work-related LBP[19]. However, the ACGIH TLVs were established for the North American working population, the limits may not accurately reflect the risk of LBP injury or disorders in Iran.

This investigation examined how accurate the adopted ACGIH TLVs at the allowable limits predict risk for LBP disorders for a group of Iranian workers using biomechanical criteria representing injury risk threshold equal to 3400 N for compression force at L4/L5[20] and 700 N for shear force at L5/S1[21]. Since the adopted Iranian guidelines provide limits for repetitive lifting, the safety margins for three categories of repetitive work were evaluated. Since no anthropometric data was available for Iranian workers at the time of testing, the expected outcome was sub-threshold loading for almost all participants, indicating that the ACGIH load limits should be adopted in Iran without modification. Furthermore, an increasing safety margin between actual and threshold criteria for compression and shear was expected for categories 2 and 3 of the Iranian Lifting Guideline which represent increasing lift repetitions and/or durations owing to the decline in injury thresholds with repetition[22, 23].

Materials and Methods

Participants

Fifteen healthy male workers who were experienced in manual material handling participated in this study in Iran after providing informed, written consent, which was approved by the Ethics Review Committee of the Ahvaz Jundishapur University of Medical Sciences.

The mean age of participants was 30.1 ± 6.1 yr and the mean work experience was 10.8 ± 4.2 yr. The mean height was 1.723 ± 0.092 m, and the mean body mass was 74.0 ± 10.5 kg (measurements were recorded using a SECA® measuring rod (Model 786, Seca Corp., Hanover, MD, USA). Participants were included in the study if they had no low back pain and history of low back surgery.

Procedures

Testing took place in the laboratory with participants completing a series of 2-handed lifting tasks as defined based on the ACGIH lifting TLV. The ACGIH lifting threshold limit value (TLVs) consist of a set of three categories. The three categories include lifting zones that are the combination of different horizontal distances of the load from the ankles (i.e. <30, >30–60, and >60–80 cm) and different vertical height of the load from the floor (shoulder, below shoulder to knuckle height, knuckle to middle of shin height, middle of shin height to floor). To use this method, after determining task duration and lifting frequency of the task, the proper TLV table is selected based on frequency of the task. Then, the lifting zone height was identified according to the initial of the hand and the horizontal location of the lift. Finally, the corresponding zone was determined and compared the lifted weight against the maximum allowable TLV (Table 1).

In the present study a total of 25 lift conditions were tested with 4 repetitions completed for each condition. The

Table 1. Allowable weight limit (kg) based on Iranian guideline for manual lifting

Category	Vertical location	Duration (h)*	Frequency (lift/h)	Horizontal Distance		
				Close (30 cm)	Intermediate (30–60 cm)	Extended (60–80 cm)
1	Shoulder	≤2	lift≤60	16 kg	7 kg	Undefined safe limits**
		≥2	lift≤12			
	Torso	≤2	lift≤60	32 kg	16 kg	9 kg
		≥2	lift ≤12			
	Knee	≤2	lift≤60	18 kg	14 kg	7 kg
		≥2	lift ≤12			
	Ankle	≤2	lift≤60	14 kg	Undefined safe limit	Undefined safe limit
		≥2	lift ≤12			
2	Shoulder	≥2	12≤lift≤30	14 kg	5kg	Undefined safe limit
		≤2	60≤lift≤360			
	Torso	≥2	12≤lift≤30	27 kg	14kg	7 kg
		≤2	60≤lift≤360			
	Knee	≥2	12≤lift≤30	16 kg	11kg	5 kg
		≤2	60≤lift≤360			
	Ankle	≥2	12≤lift≤30	9 kg	Undefined safe limit	Undefined safe limit
		≤2	60≤lift≤360			
3	Shoulder	≥2	30≤lift≤360	11 kg	Undefined safe limit	Undefined safe limit
	Torso	≥2	30≤lift≤360	14 kg	9 kg	5 kg
	Knee	≥2	30≤lift≤360	9 kg	7 kg	2 kg
	Ankle	≥2	30≤lift≤360	Undefined safe limit	Undefined safe limit	Undefined safe limit

*Classify task duration as either less than or greater than 2 h per d (8-h shift).
**Undefined safe limits: Lifting tasks should not be performed for “undefined safe limits”. Available evidence does not permit identification of safe weight limits in the conditions.

participants lifted a box (40 × 24 × 15 cm) with different weights (i.e. allowable limit values) from selected locations within four vertical zones (shoulder, below shoulder to knuckle height, knuckle to middle of shin height, middle of shin height to floor) and three horizontal distances, measuring 30 cm (close), 30–60 cm (intermediate) and 60–80 cm (extended) from the midpoint between the ankle bones at the origin of the lift. Lift heights were normalized to the body using adjustable-height shelves with the box handle used as the reference point. To specify the specific horizontal location of the load (midpoint between inner ankle bones and the load) for each lifting condition, lines were drawn on the floor. The participants were asked to keep their feet fixed on that line during all the lifting tasks (Fig. 1). The order of the lifting tasks was randomized for each participant. Participants were self-selected the style of lift with instruction to choose the most comfortable. A 30-s break was provided between each lift. To avoid muscle fatigue, a 5-min break was given every 5 min.

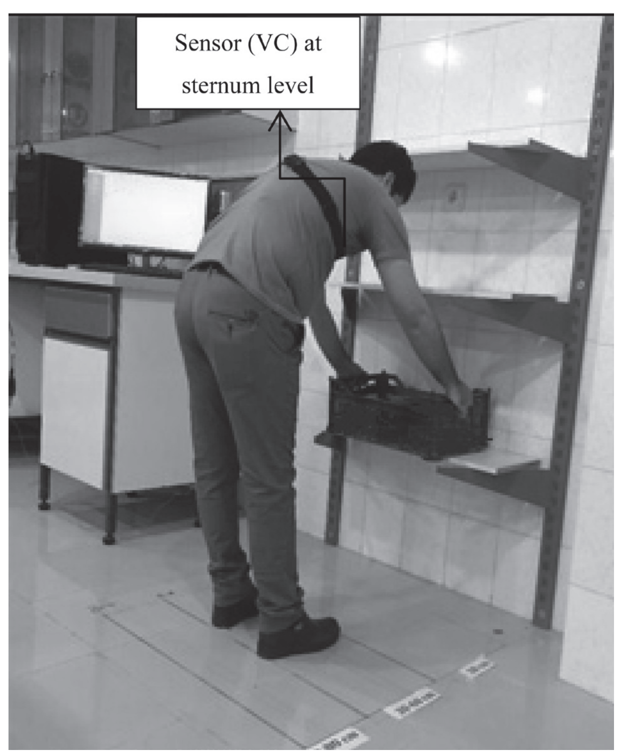

Fig. 1. Laboratory lifting station with adjustable-height shelving.

Data collection, calculations & analysis

An inclinometer and a photographic camera were used in order to collect the data needed to estimate the spinal load for each task. Trunk inclination (flexion/extension and lateral bending) was continuously recorded at a frequency of 7.5 Hz using the Virtual Corset (VC) (Microstrain, Williston, VT, USA) tri-axial accelerometer in the sagittal plane. The VC was placed over the sternum using elastic straps with Velcro™ fasteners. Trunk flexion was calculated by normalizing trunk inclination to upright standing; the reference standing posture was recorded over a 15-s window prior to commencing the lifting trials. A second reference position was recorded at the end of the trials to verify whether the VC had remained in place throughout testing.

Shoulder, leg and neck postures for each lifting task were recorded using a photographic camera (Canon HDR-HC3, Tokyo, Japan). As the lifting began, the tasks were photographed simultaneously with the online recording of trunk angles via the VC. The angles of the forearm, upper arm, upper leg, lower leg and neck were determined based on postural analysis for each lifting task.

Compression load at the L4/L5 and shear load at the L5/S1 for each lifting task were calculated using the static biomechanical model of the University of Michigan (3DSSPP, University of Michigan Ann Arbor, MI, USA). To estimate spine loads, load weight and postural data obtained at the origin along with the anthropometric data including height and weight of each participant (50th percentile) were entered into the biomechanical model.

Results

The variability in both compression and shear lumbar spine loads showed that actual loading was not uniform across lift conditions even with the graded reductions of the mass being lifted (Fig. 2). This was more pronounced for L4/L5 compression: The range in mean values for compression was 2577 N; this narrowed to 2267, 2136, and 972 N for Categories 1, 2, and 3, respectively. L5/S1 shear was more uniform with a total range of 188 N between the maximal and minimum mean values across all lift conditions. A convenient measure is 83% as this is equivalent to being within standard deviation of the mean on the positive side in a normal distribution. In Category 1, 5 of the 9 lift conditions had at least between 33 to 83% of lift trials exceeding 3400 N; between 25 to 36% of lift trials resulted in higher risk spinal compressive loads (between 20 to 83% of lift trials exceeding 3400 N) (Table 2). Of further concern is the corresponding high number of lift conditions in Categories 2 and 3 that exceeded the compressive threshold limit before factoring the effect of cumulative loading from repetitive work. Figure 3 shows high variability in trunk flexion angles for each Category.

Discussion

Based on L4/L5 compression results alone, the guideline overstated the relative safety of the majority of lift conditions at torso lift height and lower. Since lifting guidelines represent work conditions that almost all workers can be exposed to on a daily basis (over an 8-h work day) without developing work-related low back disorders from lifting, the proportion of lifts below the threshold is of highest interest. Assuming that the probability relationship between low back disorders and compressive spinal loading[24, 25], the allowable limits may not represent equal levels of risk as the guideline implies; revision of the allowable load limits for lifting would correct this.

External mass

Within each lift category, L4/L5 compression decreased as the lift height lowered, and as the forward lift distance lengthened. Prediction errors for anthropometrics are one explanation: If the sample group was lighter in mass than the reference group, L4/L5 compression would decrease with lifts in a forward-bent position. The study group proved to be lighter in body mass than the average North American according to anthropometric normative data reported by McDowell *et al.*[26] (average body mass=89.1 ± 33.9 kg), as well as, Iranian workers (average body mass=74 ± 7.8 kg), based on anthropometric data reported by Sadeghi *et al*[27]. Therefore, it was highly probable that the downward trend in L4/L5 compression with awkward trunk postures was partially a result of differences in body mass between the participant and the reference group. This would have distorted an intentional effect of uniform compressive forces on the lower lumbar spine from graded reductions in the allowable mass being lifted in awkward positions. It is important to note, that this effect would likely hold if the lifting load limits had been adjusted for Iranian workers, (but not as steep given the smaller difference between sample group and population). This trend was not surprising since body mass has an important role in the prediction of spinal loads[28].

Prediction errors for body position may have also contributed to the downward trends in L4/L5 compression. Since lift height was normalized to the individual, differences in stature between the sample and reference group should have had no influence: the lift height was not standardized to a set distance, it was normalized to an anatomical reference point on the person. Forward reach

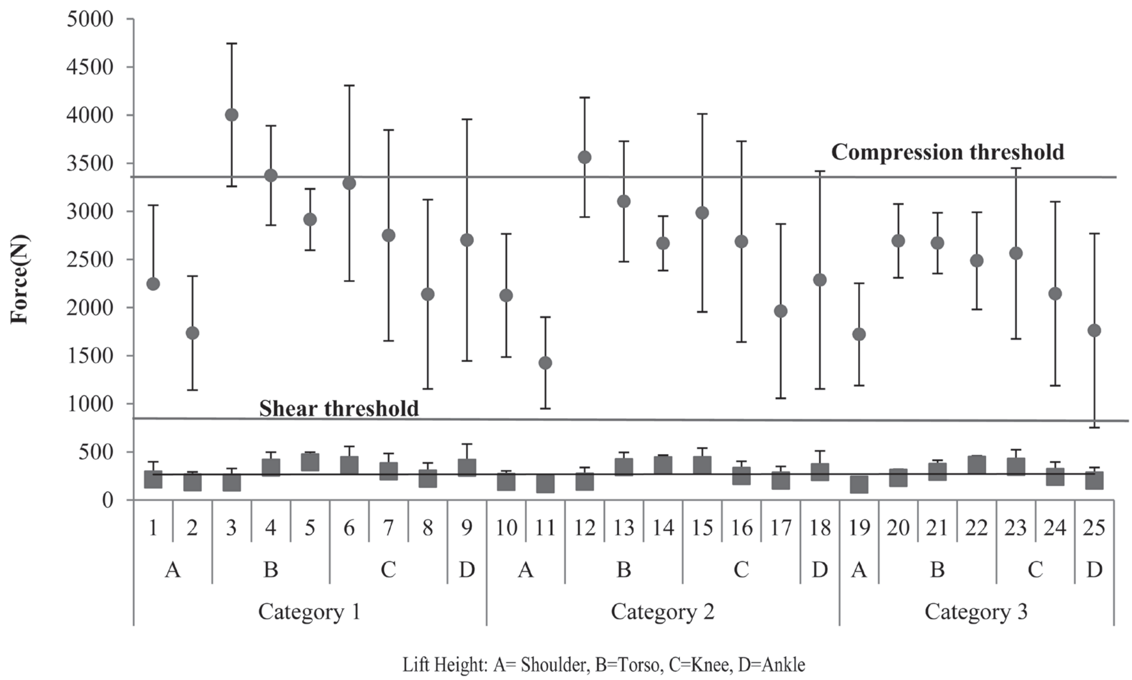

Fig. 2. Mean (SD) compression force at the L4/L5 and shear forces at the L5/S1.

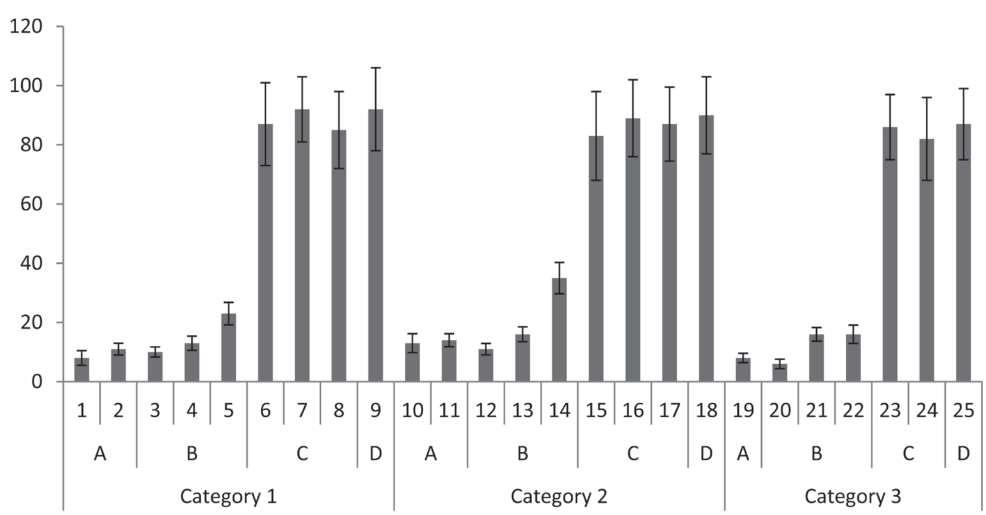

Fig. 3. Mean (SD) trunk flexion angles.

distances however, were not normalized to the individual, they were at a set distance; therefore, differences in arm length could be influential when reach distances are beyond the length of the arm, since greater trunk flexion is required to contribute to reach with shorter arms. Since arm length tends to vary with stature, and the stature between this participant group and the North Americans using data provided by Chaffin *et al.*[29], then arm length did not appear to be influential.

Lift style was self-selected and therefore, a potential source for error since stoop-style lifts require higher trunk inclination than squat-style lifts at lower lift heights[30]. If the sample group used a squat-style lift and the reference group used a stoop-style lift, then trunk flexion would be lower than expected. The high variability in trunk flexion suggests that lift style varied between study participants (Fig. 2). This variability masked any beneficial height from raising lift height to the knee from the ankle that has

Table 2. Spinal compression force at the L4/L5 and shear forces at the L5/S1 (N)

		Lift parameters			Compression force			Shear force		
		Load (kg)	Forward distance	Lift height	Mean ± SD	95% CI	#lifts >3400 N	Mean ± SD	95% CI	# lifts >700 N
Category 1	1	16	30	Shoulder	2,245 ± 819	(1,791–2,698)	2	214 ± 184	(111–316)	0
	2	7	60	Shoulder	1,735 ± 592	(1,407–2,063)	0	184 ± 108	(123–244)	0
	3	32	30	Torso	4,002 ± 742	(3,590–4,413)	30 (0.50)	182 ± 146	(101–263)	0
	4	16	60	Torso	3,373 ± 516	(2,870–3,660)	15 (0.25)	337 ± 162	(247–427)	0
	5	9	80	Torso	2,915 ± 319	(2,738–3,092)	2 (0.03)	391 ± 108	(331–451)	0
	6	18	30	Knee	3,292 ± 1,016	(2,729–3,855)	20 (0.33)	364 ± 193	(257–471)	0
	7	14	60	Knee	2,750 ± 1,096	(2,143–3,657)	20 (0.33)	299 ± 185	(196–412)	0
	8	7	80	Knee	2,138 ± 983	(1,594–2,682)	2 (0.03)	222 ± 163	(131–313)	0
	9	14	30	Ankle	2,702 ± 1,256	(2,107–3,598)	20 (0.33)	335 ± 247	(199–472)	0
Category 2	10	14	30	Shoulder	2,125 ± 640	(1,770–2,450)	2 (0.03)	189 ± 113	(126–252)	0
	11	5	60	Shoulder	1,425 ± 475	(1,162–1,688)	0	167 ± 59	(133–199)	0
	12	27	30	Torso	3,561 ± 621	(3,216–3,905)	20 (0.33)	191 ± 147	(109–273)	0
	13	14	60	Torso	3,103 ± 626	(2,567–3,438)	10 (0.23)	342 ± 154	(256–427)	0
	14	7	80	Torso	2,667 ± 282	(2,511–2,824)	0	362 ± 104	(305–420)	0
	15	16	30	Knee	2,984 ± 1,029	(2,414–3,755)	20 (0.33)	363 ± 176	(256–461)	0
	16	11	60	Knee	2,685 ± 1,044	(2,207–3,363)	14 (0.23)	250 ± 153	(165–335)	0
	17	5	80	Knee	1,963 ± 906	(1,461–2,465)	0	202 ± 148	(119–284)	0
	18	9	30	Ankle	2,287 ± 1,132	(1,760–3,114)	14 (0.23)	290 ± 220	(167–412)	0
Category 3	19	11	30	Shoulder	1,721 ± 531	(1,427–2,015)	0	160 ± 86	(112–208)	0
	20	14	30	Torso	2,693 ± 383	(2,480–2,905)	2 (0.03)	230 ± 90	(180–280)	0
	21	9	60	Torso	2,670 ± 316	(2,495–2,845)	0	293 ± 120	(226–360)	0
	22	5	80	Torso	2,486 ± 505	(2,206–2,766)	0	367 ± 92	(316–418)	0
	23	9	30	Knee	2,563 ± 887	(2,071–3,155)	8 (0.13)	346 ± 178	(247–445)	0
	24	7	60	Knee	2,144 ± 955	(1,615–2,673)	2 (0.03)	240 ± 156	(154–327)	0
	25	2	80	Knee	1,761 ± 1,008	(1,760–2,319)	0	202 ± 136	(126–277)	0

been previously shown in experimental studies[31–33]. Since lift style appeared inconsistent, it is difficult to determine whether self-selecting a lift style contributed to the downwards trend of L4/L5 compression across lift height or distance.

Lift height

The ideal lift height corresponding to the maximal allowable limit of 32 kg resulted in 83% of the trials exceeding 3,400 N. The high values were likely influenced by trunk angle: The mean inclination was 17° (SD 12°), showing that this lift height did not correspond to an upright standing posture for most study participants. Previous studies have shown large increases in spinal compression with just 10° difference when forward bent standing was less than 40°[34, 35]; therefore, small deviations from upright standing could account for an otherwise safe load limit for lifting at torso height. The revised Lift Index produced by the National Institute of Occupational Safety and Health (NIOSH) which also uses 3400 N as an injury threshold, has a comparable load limit that is 8.9 kg lighter, and is held 5 cm closer[20]. Further consideration of this reference limit is needed.

The underestimation of risk continued in Category 1 for both knee and ankle height at the nearest distance with 39% of lift trials having L4/L5 compression exceeding 3400 N, even though the reduction in allowable limit was 44% and 56% from torso to knee, and to ankle height, respectively. Sub-threshold loads for most participants did not occur until the lifting load decreased by 72%, to 9 kg. Experimental studies have shown that a reduction in vertical distance from the torso to an approximate knee height, should correspond to an approximate 60% reduction in the maximum allowable weight in order to maintain the L5–S1 compressive load at 3400 N[32]. Excessive trunk flexion for some participants would cause higher L4/L5 joint compression since studies have shown that bending forward for lifting from lower heights from upright standing produces as much as 255% increase in intradiscal pressure depending on the weight held in the hand[15]. Lifts at shoulder height were not hazardous for the low back. At this height, mechanical failure thresholds for the lumbar spine are less important than physiological loading criteria for the shoulder[20] owing to the shift in biomechanical joint loading from the low back to the shoulders[36].

Forward lift distance

Sub-threshold lumbar compression for most participants in Category 1 did not occur with the moderate distance at torso height even with the 50% reduction in lift load; at far distance, the 9-kg load (72% reduction) was below threshold for all participants. At knee height, sub-threshold loads occurred at the moderate distance with the 56% reduction in weight from 32 kg. *In-vivo* studies have shown that when the horizontal distance for lifting increases from 25 to 50 cm, the maximum hand load should have decreased by approximately 40% in order to maintain 3400 N compression at L5/S1[15].

Lift repetition

Exposure to cumulative compressive loads has been shown to be an important and independent predictor of back pain[14, 17]. Between categories, L4/L5 compression trended downwards as expected given the further reduction in allowable limits. A previous *in vivo* study for compressive strength showed that failure occurred for loads between 30 and 75% of peak loads with repetitive loading[22]; the exposure here surpasses the upper limit of 75% of 3400 N for many lifts conditions in Category 2 and some in Category 3. The categories result in a broad range of cumulative loads; moreover, the guideline does not account for loading from different work tasks when a worker performs a variety of lifting tasks during a working shift. This analysis was restricted to instantaneous loading and consideration of the margins between threshold and actual loading; however, a further detailed analysis is required to determine if Categories 2 and 3 require further separation.

Limitations

Simple risk assessment tools for lifting that are based on lumbar spine loading and that only require task parameters have trade-offs in accuracy when the target user group differs from the reference group for body mass. This participant group did not appear to represent either the North American or Iranian reference group; thereby, only inferences could be made regarding the accuracy of the lifting guidelines. The small sample size may have contributed to this problem; nonetheless, it raises an important issue on the application of these tools. This sample group may have easily represented an actual group of workers, without a clear understanding of this limitation; employers may not be making the best decisions with this tool.

The 3DSSPP is a more refined risk assessment for employers and not subject to the same errors as simple risk assessment tools since both individual and task parameters are used as inputs. Nonetheless, it is restricted to a static analysis and thereby, underestimates actual loading by not including dynamic moments[37, 38] which have been reported to increase L5/S1 compression by 21–70% depending on lift pace[29].

This study was restricted in scope as only the accuracy to predict established injury risk thresholds was considered; it did not address factors that influence the compressive strength of the lumbar spine and thereby, alter the threshold. For example, a loss of bone mineral content with aging will result in a diminished injury threshold[22]. This is an important limitation of many risk assessment tools which employers may not be aware of. The simplicity of load limits as risk assessments are particularly concerning as employers may underappreciate the complexity of LBP disorders and their causes. Based on the findings here, these adopted guidelines as standing provide no margin of safety for anyone with lower injury thresholds.

Conclusion

Based on the L4/L5 compression results alone, the adopted ACGIH TLVs overstate the safety of the majority of lift conditions at torso height and lower for this sample group of Iranian workers, assuming a 3,400 N injury threshold for an elevated risk of low back disorders. The loads held at torso height and close to the body were more likely to produce excessive spine compression, indicating that the reference load of 32 kg should be lowered. Since differences in anthropometrics between this sample group and North Americans distorted the effect of gradations in allowable load limits on lumbar spine compression, the TLVs should be redesigned to match with Iranian workers. Furthermore, assumptions for lift style should be clarified as this was an important source of variation. Last, the reduction in loads for repetitive lifting appeared poorly considered and inadequate for safe work. Since government, employers and workers may be under the assumption that the workplace is relatively safe and no remedial action is needed, these allowable limits should be redesigned in a way that minimizes prediction errors for this simple risk assessment tool, and addresses a broader set of threshold criteria.

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