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Original Article

Ergonomic Risk Assessment and Fatigue Analysis During Manual Lifting Tasks in Farming Activities

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ABSTRACT

Introduction: Farming is a physically demanding occupation that puts farmers at risk of musculoskeletal disorders, particularly when frequently performing activities like heavy lifting, which strains the lower back muscles. The present study is aimed to assess the ergonomic risk and fatigue during manual lifting tasks of farming activities.

Methods: A study was performed on 20 farmers to analyse the ergonomic risks associated with load lifting by estimating the Recommended Weight Limit and Lifting Index using the revised NIOSH lifting equation. The low back compression forces of the participants were estimated using the 3DSSPP software. Surface electromyography was employed to analyse the onset of muscle fatigue during the lifting activity.

Results: The results of the study showed a 111.12% increase in the recommended weight limit, a 52.77% reduction in lifting index, and a 28.15% reduction in the low back compression forces for the redesigned lifting technique. The average low-back compression force for the redesigned technique was observed to be well below the back compression design limit of 770 lb. A reduction in the slope of the RMS voltage regression line by 60% and a reduction of 50.23% in the peak spectral power of the sEMG signal, accompanied by a shift in the peak spectral power towards higher frequency region indicated delayed onset of fatigue for the redesigned technique.

Conclusion: The outcomes of the study indicated that the ergonomic redesign of the lifting task could significantly reduce the lifting index and alleviate the spinal compression forces well within the back-compression design limit. The redesign was also found to delay the onset of fatigue in the erector spinal muscles.

Keywords: Ergonomic risk, Manual lifting, Muscle fatigue, sEMG, Spinal compression force

Introduction

Agriculture is one of the most practised professions and is a vital source of revenue for developing countries. It is also the primary source of food, money, and employment for rural populations. More than half of the working population in India is involved in agriculture and allied activities.[1] However, farming is a physically demanding occupation with a potential risk of musculoskeletal disorders (MSDs). Each activity in agriculture brings about a certain level of stress on the muscles and bones leading to work-related MSDs.[2] Such problems represent a major cause of absence from work and may ensue considerable financial liability to the worker. Particularly, low back pain arising from frequent lifting and lowering loads, improper postures, and heavyweight handling is regarded as the most predominant form of MSDs in farming occupation.[3] Farmers generally accept pain as a normal element of their work and only seek medical attention when the problem becomes incapacitating.

Appropriate analysis and ergonomic interventions are required to alleviate MSD-related health issues and increase work efficiency. Several techniques have been proposed for assessing the manual lifting tasks that may lead to MSDs. Among these, the revised National Institute for Occupational Safety and Health (NIOSH) lifting equation and the University of Michigan 3-dimensional static strength prediction program (3DSSPP), have gained wide acceptance owing to their simplicity and quantitative nature.[4,5]

The revised NIOSH lifting equation can be used to evaluate the possible ergonomic risks from two important measurands viz; the Recommended Weight Limit (RWL) and Lifting Index (LI). RWL is defined as the weight of the load that can be lifted over a while for a certain set of conditions with minimal risk of occurrence of MSDs. Whereas, the Lifting Index (LI) compares the load to be lifted with the RWL and offers a relative estimate of the physical stress associated with a manual lifting job. Reduced injury risk is indicated by lower values of LI, preferably less than 1, and vice versa. Meepradit et al,[6] utilised the revised NIOSH lifting equation to identify the risks associated with lifting a box containing auto parts and found the LI to be greater than 1, implying a high risk of MSDs. LI was brought down by redesigning the task with the help of recommendations as per the NIOSH standards.

In the present work, a comprehensive analysis of the manual lifting techniques associated with farming activities has been performed using the revised NIOSH Lifting Equation, 3DSSPP, and sEMG. The measurements obtained were analysed for possible ergonomic risks to the farmers. The effect of redesigning the lifting task on the physical stress associated with the task, compressive force in the lower back, and muscle fatigue characteristics were also determined.

Methods

The study was designed for the farmers of Udaipur, Rajasthan, India. A group of twenty farmers having an age of 25.2 ± 3.18 years with a height of 163 ± 7.06 cm volunteered for the activity. The sampling technique is the condition that, the farmers have neither undergone any spinal surgery nor been clinically diagnosed with chronic low back pain. All the farmers signed a written consent form for performing the lifting task. The data required for the study was collected for 20 days. The data collection technique followed for the study is described below.

The data was collected in two stages, the first being the selection of farmers, identifying the history of back injury, and collecting their anthropometric data. In the second stage, each farmer was asked to lift the loaded container filled with 20 kg of wheat from the ground level to their head. Figure 1 shows the task sequence, which comprises grasping the container, lifting it, and placing the container on the head. During this stage, the data variables such as horizontal distance of load, vertical distance of load, height through which the load was lifted, and the frequency of the lifting task were measured.

The Recommended Weight Limit (RWL) and Lifting Index (LI) were determined using the revised NIOSH Lifting Equation. RWL is given by the following equation.

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

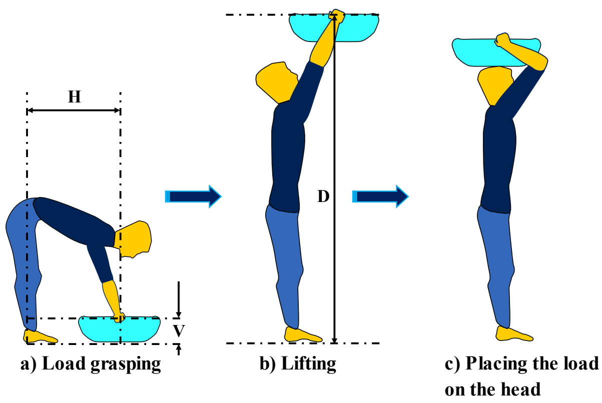

Figure 1: Sequence of Lifting

In the Equation (1), LC is the load constant, taken to be 23 kg. The multipliers such as Horizontal Multiplier (HM), Vertical Multiplier (VM), Distance Multiplier (DM), Asymmetric Multiplier (AM), Frequency Multiplier (FM), and Coupling Multiplier (CM) were calculated with the help of the equations given in Table 1.[7] The variables in Table 1, viz; H, V and D, corresponding to HM, VM and DM respectively are represented in Figure1. Here, H represents the horizontal distance of the object from the individual, V represents the vertical distance of the palm from the ground during load grasping and D represents the distance travelled by the object vertically before being placed on the individual's head. Psychophysical and biomechanical studies show reduced maximum weight limits and isometric lifting strength for asymmetric lifting tasks compared to symmetric ones.[8,9] In this study, no twisting occurred, resulting in an asymmetry angle approximation of zero and an AM value of 1. The frequency multiplier came out as 0.84 for a lifting frequency of 2 lifts/min and work duration between 1 and 2 hours, from the frequency multiplier table of the revised NIOSH lifting equation.[7] The value of the Coupling Multiplier (CM) can be 0.90, 0.95 and 1.00. The selection of value depends on vertical height and coupling quality. Loads with proper couplings or handles are easier to lift and lessen the risk of the load falling.[9] The CM in the present study is obtained as 0.95 for a vertical height of the object from the ground below 30 inches with a container of fair gripping quality.

Table 1. Calculation of multipliers used in NIOSH Lifting Equation.[10]

Multiplier	Formula Used	Variable	Variable Description
Horizontal Multiplier (HM)	HM=(25/H)	H	Horizontal location of the load from the subject
Vertical Multiplier (VM)	VM=(1-0.003∣V-75∣)	V	Vertical Location of the load from the floor
Distance Multiplier (DM)	DM=(0.82+(4.5/D))	D	The distance the object moved vertically
Asymmetric multiplier (AM)	AM=(1-(0.0032A))	A	Asymmetry Angle
Frequency Multiplier (FM)	NIOSH frequency multiplier table	F	Frequency and duration of lifting activity
Coupling Multiplier (CM)	NIOSH coupling multiplier table	C	Quality of grip on the object (poor, good, fair)

The lifting index (LI) was estimated from the following equation:

$$LI = \frac{\text{load Weight}}{RWL} \quad (2)$$

Where, 'load weight' is the weight of the object to be lifted, which is 20 kg of wheat in the present study. According to the NIOSH guidelines, lifting tasks with an LI>1 is likely to aggravate the risk of lower back pain. Hence, it is desirable to achieve an LI value of 1 or less.

While performing any lifting activities, the spine region is subjected to back compression force and this is caused by ground reaction force, gravity, and muscular/ligament contractions, with the L4/L5 disc being the most vulnerable site for instability.[11,12,13] To study the risk of low back instability in different applications, 3DSSPP software has been widely used to assess the posture and suggest appropriate corrections for performing the tasks.[14] The tool has been widely used to predict the spinal compressive force acting at the L4/L5 intervertebral disc using anthropometric, hand load, and posture data of the worker. Don B Chaffin and Muzaffer Erig[15] performed a detailed empirical comparison of a 3D static strength prediction model with a set of strength performance data and observed that with good postural data, the model was capable of predicting the mean static strength of a given population. Beyrami et al.,[16] adopted this method to estimate the forces exerted on the lower back in young workers during manual lifting tasks. Around 40% of the workers were found at high risk of suffering low back pain. Silvetti et al.,[17] used 3DSSPP to analyse the lumbar disc compression force at L4/L5 in a group of sea fishermen and predicted a lower to medium level of risk of injury for the lower back. Despite several kinds of research on the application of the above techniques for various industrial activities, the use of 3DSSPP in assessing the ergonomic risks associated with farming activities remains largely unexplored. To calculate the lower back compression force using 3DSSPP, the anthropometric data of the participants were recorded first. Following this, the photograph of the worker performing the lifting task was captured and the 3D model generated by the software was processed to estimate the low back compression force.

It is also important to understand that, during any manual lifting activity, the required extensor force is provided by the erector spinae muscle group, which spans almost all along the spine. During lifting tasks, the erector spinae muscles gradually undergo fatigue and hinder voluntary task performance. The fatigue experienced by these muscles increases with the increase in the duration of the lifting activity, especially for the muscles located near the L4-L5 disc interspace. Fatigue accumulation, if not resolved, leads to overwork, chronic fatigue syndrome, and even a threat to human life.[18] Hence, estimating the muscle activity and fatigue behaviour due to repetitive loads is essential to prevent musculoskeletal injuries in workers. Various methods are available to assess muscle fatigue characteristics among which, acquiring muscle signals by surface electromyography (sEMG) is the most commonly used non-invasive technique and has been well-reported by many researchers.[19] sEMG records the variation in myoelectric signals as a manifestation of the biochemical and physiological changes in muscles during fatigue. For this, sEMG uses several fatigue indices such as the root mean square (RMS) voltage and the power spectral density (PSD).[20] Over the past decade, sEMG has gained wide acceptance in predicting the fatigue levels of various muscle groups for applications such as sports, ergonomics, occupational and medical, etc.[21]

To estimate muscle fatigue in the present work, surface electromyography (sEMG) equipment (Make: Delsys® Model: Trigno™ Wireless Biofeedback System) was used. Before attaching the sensors to the participant, the subjects had their skin shaved, scrubbed, and wiped with alcohol. The sensor input range was fixed to 11 mV. The location of the sensors on the erector spinae muscles was identified by referring to the guidelines put forth by SENIAM.[22] Accordingly, the sensors were positioned on the participants at the Thoracolumbar Fascia at the level of their L4-L5 interspace, and 2 cm lateral to the midline using hypoallergenic adhesives. The placement of sensors for one of the participants is shown in Figure 2. The sensor electrodes were spaced 1 cm apart and aligned parallel to the muscle fibres. The raw EMG data of the muscle activity was recorded using the data acquisition software (DELSYS EMGworks® Acquisition Software) at a sampling rate of 2148 Hz. The raw EMG signal was first filtered using a bandpass filter of 10-450 Hz. Then, the EMG signal was converted to the RMS value using a moving RMS calculation procedure. The time window length considered was 0.125 seconds and the window overlap was 0.0625 seconds. In order to manifest the fatigue characteristics of the muscle group, the raw EMG data was post-processed to obtain the RMS voltage regression line and the power spectral density curve.[23,24]

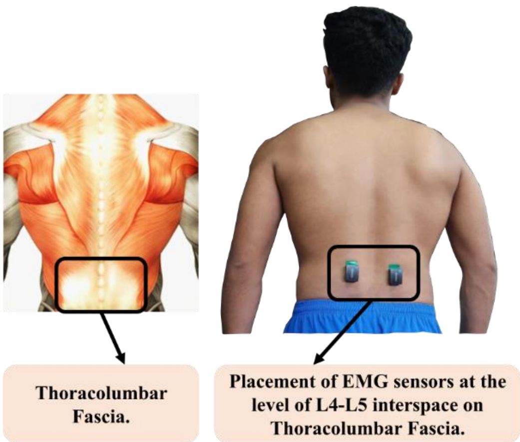

Figure 2: Depiction of the muscles corresponding to L4/L5 interspace (left) and Placement of EMG sensors (right)

Results

After the completion of data collection, the RWL and LI were calculated with the help of the multipliers provided in Table 1. The frequency multiplier and coupling multiplier were obtained from the standard tables provided in the application manual for the NIOSH Lifting Equation.[7] The asymmetric multiplier was estimated to be “1” as calculated using the equation given in Table 1. The RWL and LI values calculated for all 20 farmers are given in Table 2. The 3DSSPP postural model of one of the volunteers performing the lifting task is shown in Figure 3.

The low back compression force estimated from the 3DSSPP analysis is also presented in Table 2.

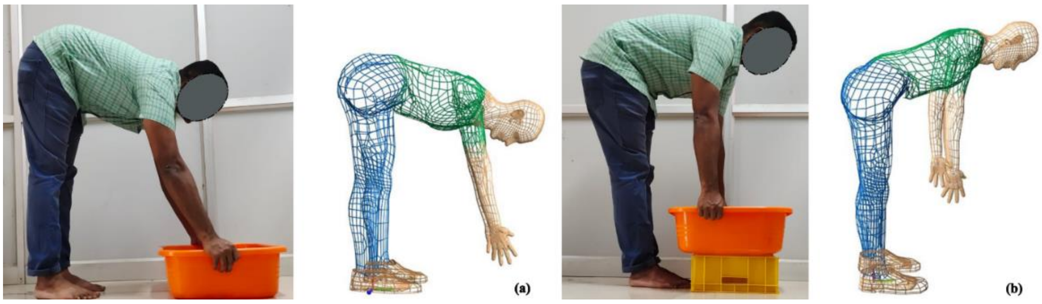

Figure 3: 3DSSPP Postural model of the volunteer during flexion for load grasping - (a) before redesign and (b) after redesign.

Table 2. Statistics of variables, multipliers RWL, LI, and back compression force for the lifting task before redesign

Subject	Height (in cm)	Age (Years)	Hand Location (Initial)		Distance Travelled (D_1) (cm)	HM	VM	DM	RWL (kg)	LI	3D Back Compression Force (N)
			Horizontal Distance (H_1)(cm)	Vertical Distance (V_1) (cm)							
1	157	22	46	12	168	0.543	0.811	0.847	6.846	2.921	3981.156
2	170	28	53	13	175	0.472	0.814	0.846	5.966	3.352	3918.880
3	157	28	48	12	161	0.521	0.811	0.848	6.576	3.041	3558.575
4	155	32	57	12	158	0.439	0.811	0.848	5.541	3.609	4648.389
5	170	27	57	13	175	0.439	0.814	0.846	5.549	3.604	4354.806
6	165	22	48	12	171	0.521	0.811	0.846	6.561	3.048	4016.742
7	168	25	44	12	169	0.568	0.811	0.847	7.161	2.793	5933.924
8	160	21	48	12	166	0.521	0.811	0.847	6.569	3.045	5208.864
9	160	29	54	13	162	0.463	0.814	0.848	5.866	3.409	4114.602
10	171	23	55	12	168	0.455	0.811	0.847	5.736	3.487	3224.959
11	145	22	52	12	166	0.481	0.811	0.847	6.064	3.298	3598.609
12	168	23	58	12	178	0.431	0.811	0.845	5.421	3.689	4274.738
13	160	31	48	13	172	0.521	0.814	0.846	6.585	3.037	3545.230
14	161	27	47	12	168	0.532	0.811	0.847	6.707	2.982	4670.630
15	158	25	50	12	169	0.5	0.811	0.847	6.304	3.173	3754.297
16	170	24	48	12	170	0.521	0.811	0.846	6.561	3.048	4279.1867
17	172	24	55	12	172	0.455	0.811	0.846	5.73	3.49	4123.499
18	172	25	53	12	173	0.472	0.811	0.846	5.944	3.365	3580.816
19	163	22	51	12	166	0.49	0.811	0.847	6.178	3.237	3732.0557
20	160	23	51	13	165	0.49	0.814	0.847	6.201	3.225	4314.772
Average	163.1	25.15	51.15	12.25	168.6	0.491	0.812	0.8467	6.203	3.242	4141.737

From Table 2, the average RWL, LI, and low back compression force were found to be 6.20 kg, 3.24, and 4141.737 N respectively. The mean LI being greater than 3 indicates that the lifting task is highly stressful. Continued adoption of this lifting technique may thus lead to muscle fatigue and eventually musculoskeletal disorders (MSDs).[7,25]

Table 2 also indicates that the mean back compression force at L4/L5 was higher than the Back-Compression Design Limit BCDL of 770 pounds[26], which is approximately 3425.129 N implying a substantial risk of lower back pain. Hence, it becomes necessary to redesign this lifting task to reduce the risk of MSDs. Accordingly, the lifting tasks were modified by following the recommendations put forth by Waters et al.[7] An artistic impression of the lifting before and after the redesign is presented in Figure 4.

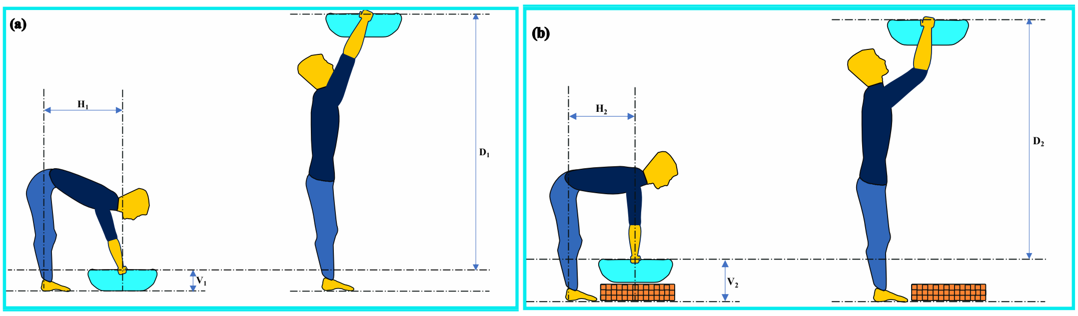

Figure 4: Artistic impression of the lifting task - (a) before redesign and (b) after redesign. Here $H_2<H_1$, $V_2>V_1$ and $D_2<D_1$

The following modifications were carried out for the ergonomic redesign of the lifting task.

1. The initial lifting position of the hand was changed by reducing the horizontal distance between the hand and the body by keeping the load closer to the body (i.e. from H_1 to H_2, where $H_2<H_1$) and by raising the vertical height of the load by keeping the load on a platform and lifting it from that position (i.e. from V_1 to V_2, where $V_2<V_1$).
2. The height through which the load was lifted beyond the head level was also reduced to minimise the distance moved by the hands (i.e. from D_1 to D_2, where $D_2<D_1$).
3. The coupling multiplier is influenced by the grip of the hand on the object and the vertical distance of the hand from the ground during load grasping. The greater the coupling multiplier, the better the handling capabilities. To improve this multiplier, the farmers were instructed to apply a strong grip and hold the container while lifting. By doing this, the coupling multiplier was increased from 0.95 to 1.

Here, V_1 is the height at which the load is gripped, measured from the ground before the task redesign, and measured as 17 cm. V_2 is the height at which the load is gripped, after adding an extra platform and is increased to 31 cm. Here, the platform height is 14 cm, maintained the same for all the participants of the study.

Similarly, H_1 and H_2 are horizontal distances of the load grasping measured from the individual's coronal axis, in the case before modification and after modification respectively. These distances were fixed at 60 cm and 30 cm respectively, with a difference of 30 cm. D_1 and D_2 are the vertical distances traveled by the load, before and after the modification. In the initial task, the participants lifted the load with the arms completely stretched atop the head. While in the modified tasks, the participants lifted the load from the platform to the tip of their head, without completely stretching the arm. These distances vary concerning the heights of the participating individuals.

After the modifications in the lifting task, the RWL and LI values were re-estimated, and the data is presented in Table 3. Figure 3(b) depicts the 3DSSPP postural model after the ergonomic redesign of the task. The back-compression force estimated from the analysis is also presented in Table 3.

The average RWL, LI, and back compression force after the redesign of the task were 13.09kg, 1.53, and 2975.64 N, respectively, when compared to the corresponding values of 6.20 kg, 3.24, and 4141.74 N obtained from the previous lifting technique. There was a 111.12% increase in RWL, a 52.78 % reduction in LI, and a 28.25% reduction in back compression force after the modification in the lifting task. An increase in RWL implies that a farmer who was earlier recommended to lift a maximum load of 6.20 kg is now capable of lifting a load of nearly 13.09 kg without any risks of MSDs.

After obtaining the results of RWL, LI, and back compression forces, the analysis was further extended to study the fatigue behaviour of the erector spinal muscle. For this, the surface electromyography voltage signals of the target muscle group were captured and post-processed to obtain the RMS voltage regression lines and the power spectral density curves.

A total of 10 cycles, with 1-minute rest interval between cycles, consisting of erector spinae flexion (for grasping the load) and extension (for lifting the load) activities, were performed by each volunteer before and after the task redesign.

Table 3. Statistics of variables, multipliers RWL, LI, and back compression force for the lifting task after redesign

Subject	Height (in cm)	Age (Years)	Hand Location (Initial) Horizontal Distance (H_2)(cm)	Hand Location (Initial) Vertical Distance (V_2) (cm)	Distance Travelled (D_2) (cm)	HM	VM	DM	RWL (kg)	LI	3D Back Compression Force (N)
1	157	22	29	30	140	0.862	0.865	0.852	13.735	1.456	3349.509
2	170	28	30	28	156	0.833	0.859	0.849	13.134	1.523	2886.894
3	157	28	32	33	137	0.781	0.874	0.853	12.588	1.589	3091.512
4	155	32	32	33	136	0.781	0.874	0.853	12.588	1.589	3118.201
5	170	27	28	30	153	0.893	0.865	0.849	14.179	1.411	2602.208
6	165	22	29	30	150	0.862	0.865	0.85	13.702	1.46	2464.313
7	168	25	27	29	150	0.926	0.862	0.85	14.669	1.363	3220.51
8	160	21	30	32	141	0.833	0.871	0.852	13.365	1.496	3087.064
9	160	29	33	30	145	0.758	0.865	0.851	12.063	1.658	3300.578
10	171	23	34	34	148	0.735	0.877	0.85	11.846	1.688	2820.171
11	145	22	27	29	130	0.926	0.862	0.855	14.755	1.355	2548.829
12	168	23	34	35	146	0.735	0.88	0.851	11.9	1.681	3496.3
13	160	31	33	30	144	0.758	0.865	0.851	12.063	1.658	2731.206
14	161	27	28	30	144	0.893	0.865	0.851	14.212	1.407	3336.164
15	158	25	32	31	138	0.781	0.868	0.853	12.502	1.6	2793.481
16	170	24	31	31	151	0.806	0.868	0.85	12.857	1.556	2606.656
17	172	24	32	34	150	0.781	0.877	0.85	12.587	1.589	3167.132
18	172	25	31	28	156	0.806	0.859	0.849	12.708	1.574	3158.235
19	163	22	29	33	143	0.862	0.874	0.851	13.861	1.443	2660.035
20	160	23	32	31	141	0.781	0.868	0.852	12.487	1.602	3073.719
Average	163.1	25.15	30.65	31.05	144.95	0.819	0.868	0.851	13.090	1.534	2975.636

A rest time of 30 minutes was given between the original activity and the redesigned activity, to avoid data discrepancy. Figure 5 shows EMG voltage data for a volunteer's left Thoracolumbar Fascia muscle during pre and post-redesign lifting tasks, indicating a significant reduction in EMG voltage potential after the redesign. An expanded image of the EMG graph of the same data is presented in Figure 6 to clearly show the variation in EMG voltage potential between conventional and redesigned lifting techniques.

To further understand the effect of task redesign on muscle activation and the onset of muscle fatigue, the RMS voltage regression graph and the power spectral density distribution of the EMG signal of the volunteers were obtained. The RMS voltage regression line for one of the volunteers before and after the task redesign is shown in Figure 7(a). Figure 7(b) shows the power spectral density distribution of the volunteers before and after task redesign.

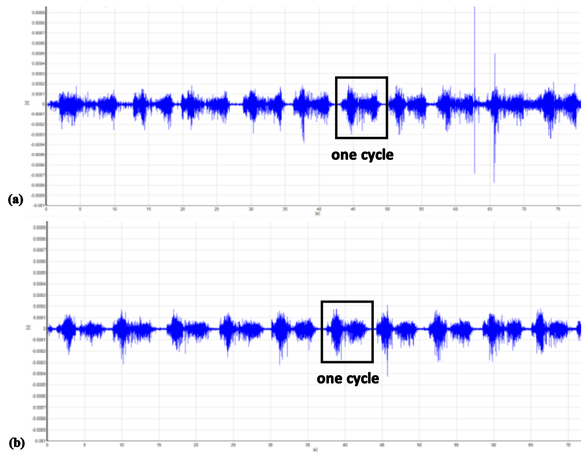

Figure 5: EMG data of a participant (a) before the redesign and (b) after the redesign

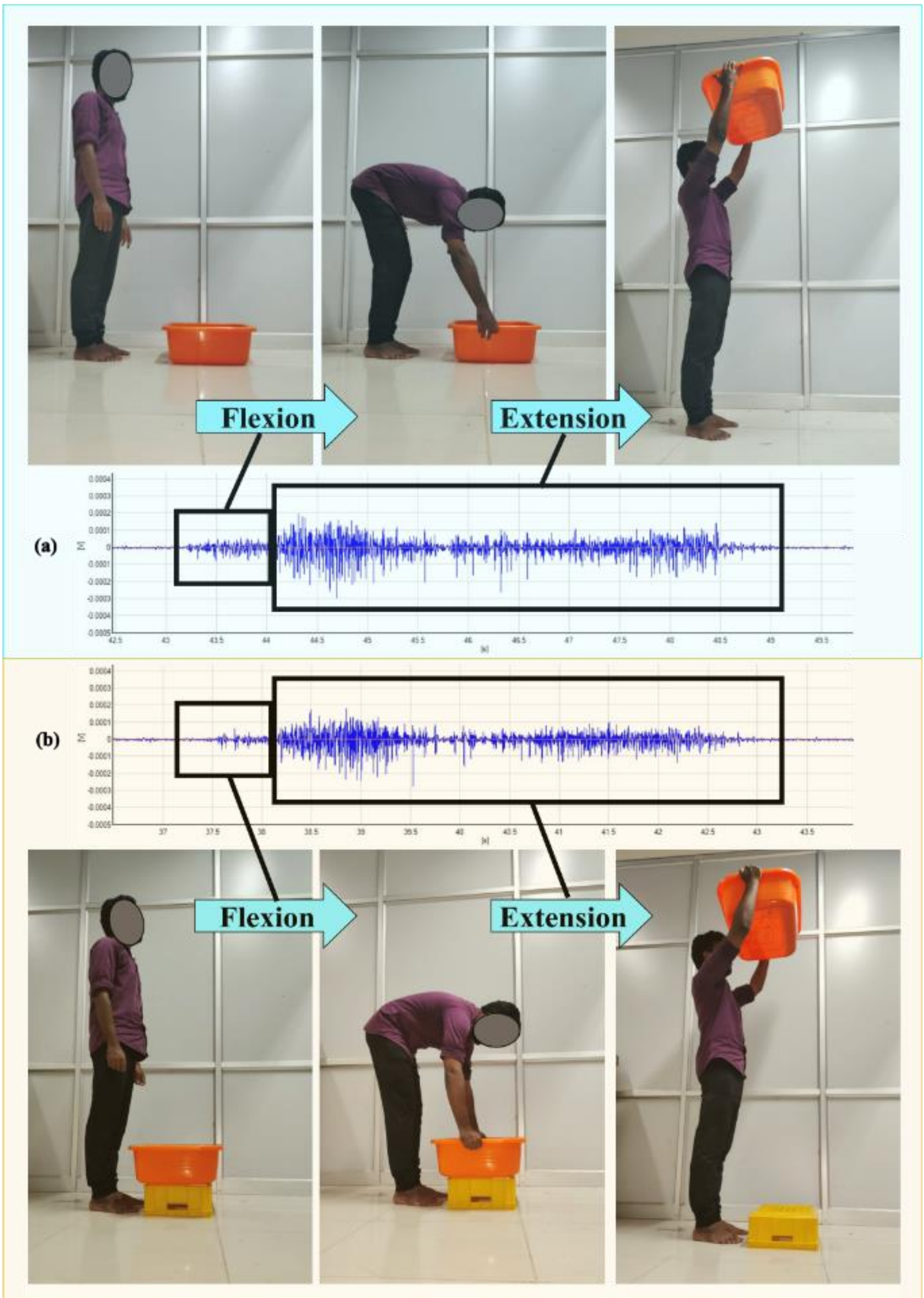

Figure 6: Sequence depicting the tasks and EMG data of lifting operation
(a) Before task redesign and (b) After task redesign.

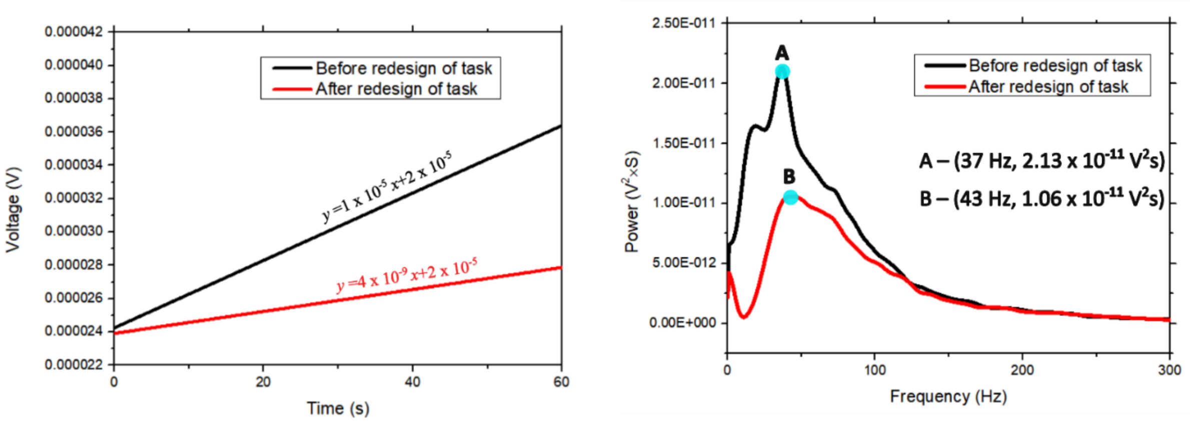

Figure 7: (a)RMS voltage regression lines before and after task redesign
(b) Power spectral density curves before and after task redesign

Table 4. RMS voltage regression slopes and power spectral density points for different volunteers.

RMS voltage regression line slope			Power spectral density data points			
Subject	**Before redesign**	**After redesign**	**Before redesign**		**After redesign**	
			Power (V^2 s)	**Frequency (Hz)**	**Power (V^2 s)**	**Frequency (Hz)**
1	3.00×10^{-08}	1.20×10^{-08}	5.00×10^{-11}	53	4.00×10^{-11}	60
2	2.00×10^{-08}	8.00×10^{-09}	4.28×10^{-11}	47	2.78×10^{-11}	53
3	1.50×10^{-08}	6.00×10^{-09}	3.28×10^{-11}	39	1.28×10^{-11}	47
4	2.25×10^{-08}	9.00×10^{-09}	4.90×10^{-11}	51	3.60×10^{-11}	58
5	1.30×10^{-08}	5.20×10^{-09}	2.20×10^{-11}	43	1.20×10^{-11}	48
6	3.20×10^{-08}	1.28E-08	5.10×10^{-11}	51	3.10×10^{-11}	59
7	1.60×10^{-08}	6.40×10^{-09}	4.10×10^{-11}	43	2.60×10^{-11}	50
8	2.00×10^{-08}	8.00×10^{-09}	3.10×10^{-11}	48	1.80×10^{-11}	54
9	1.00×10^{-08}	4.00×10^{-09}	2.13×10^{-11}	37	1.06×10^{-11}	43
10	2.50×10^{-08}	1.00×10^{-08}	4.70×10^{-11}	51	3.70×10^{-11}	58
11	1.00×10^{-08}	4.00×10^{-09}	2.13×10^{-11}	36	6.30×10^{-12}	42
12	1.90×10^{-08}	7.60×10^{-09}	4.10×10^{-11}	46	3.10×10^{-11}	51
13	2.60×10^{-08}	1.04×10^{-08}	4.80×10^{-11}	48	2.80×10^{-11}	55
14	2.20×10^{-08}	8.80×10^{-09}	3.10×10^{-11}	45	2.10×10^{-11}	53
15	1.80×10^{-08}	7.20×10^{-09}	2.32×10^{-11}	41	1.32×10^{-11}	47
16	2.90×10^{-08}	1.16×10^{-08}	4.80×10^{-11}	50	3.30×10^{-11}	57
17	1.70×10^{-08}	6.80×10^{-09}	2.40×10^{-11}	40	1.10×10^{-11}	45
18	2.10×10^{-08}	8.40×10^{-09}	4.51×10^{-11}	44	3.01×10^{-11}	52
19	1.10×10^{-08}	4.40×10^{-09}	2.00×10^{-11}	38	1.00×10^{-11}	43
20	1.50×10^{-08}	6.00×10^{-09}	3.00×10^{-11}	41	2.00×10^{-11}	48

The slope values of RMS voltage regression lines and the data points of power spectral density for all 20 volunteers before and after the task redesign are given in Table 4.

Discussion

From the data presented in Tables 2 and 3, it may be inferred that the risk of back injury for farmers while lifting 20 kg of weight after the redesign will be much lesser than that of the lifting technique followed previously, as the mean value of LI has been reduced from 3.24 to 1.5.

Besides the fact that the reduction in back compression force is quite evident after the redesign, it is worth noting that the average back-compression force value has been brought down from 4141.74 N to 2975.64 N which is much below the Back-Compression Design Limit (BCDL) of 3425.129 N implying that the stresses exerted on L4/L5 are now within safe limits.

A similar trend is observed while analysing the sEMG results of the participants. A clear reduction in the intensity of EMG signal was observed for the redesigned task (Figure 6 (b)) compared to the original task (Figure 6(a)). The reduction in the EMG voltage potential signifies a reduction in the muscle activity of the participant after the redesign of the task.[31]

The low EMG activity during flexion in the redesigned task can be attributed to the fact that the volunteer's range of bending was reduced due to the addition of a platform to increase the vertical distance at which load was placed ($V_2>V_1$) and due to the reduction of horizontal distance between the volunteer's coronal plane and the weight to be lifted ($H_2<H_1$). Similarly, the low EMG activity during extension (load lifting) is attributed to the reduced distance of travel (D) after the task redesign.

The RMS voltage regression lines with nearly the same voltage intercepts (shown in Figure 7(a)) depict that the muscles are at the same initial state before lifting the load (both in the case of the old lifting technique and the redesigned technique). Yet another interesting observation is the differences in the slope of the RMS regression line. From Figure 7(a), the slope of the RMS voltage of the old lifting technique was 1×10^{-8}, while it was 4×10^{-9} for the redesigned activity. A higher slope signifies higher firing rates of the individual motor units for the same period, which gives evidence of early muscle fatigue for the old lifting activity compared to the redesigned lifting activity.[27,28] The slope of the regression line has reduced by as much as 60% after redesigning the task, indicating a reduction in the onset of muscle fatigue.

Similarly, the power spectral density distribution shown in Figure 7(b) indicates a reduction in the peak spectral power by approximately 50.23% post-redesign of the task. Besides, there has been a shift in the peak power frequency towards the positive x-axis. As can be noted from Figure 7(b), the peak power, initially observed at 37 Hz, has shifted to 43 Hz after redesigning the lifting activity. The reduction in peak power is attributed to the lowered release of voltage potential from each motor unit, while the increase in the peak power frequency might be due to the recruitment of more motor units in lifting the given load thereby lowering the burden on individual motor units. As a result, the muscle group experiences delayed onset of fatigue.[27,29,30]

Similar results were observed for all the volunteers as evident from Table 4. The slope of the voltage regression line decreased for the lifting task after redesign for each volunteer. It can also be observed that the frequency values increased, and peak power values decreased for all the volunteers after the task redesign.

Overall, the findings of this study reveal that musculoskeletal problems in farmers can be reduced by the systematic redesign of lifting techniques. The outcomes of this study would serve as a framework to analyse the risk associated with any manual lifting activity and help to devise appropriate postural modifications to lower the risk of injuries.

Conclusions

In this study, the ergonomic risk assessment was performed for the lifting techniques used by the farmers. The initial findings revealed that the risk of low back discomfort in farmers was extremely high, indicating the presence of physical overload and poor lifting method which involves over-flexion and over-extension of the erector spinae muscle group. To mitigate the same, the recommendations proposed in the literature were taken into consideration and the lifting task was redesigned. The various parameters that helped analyse the risk associated with the lifting task were calculated using analytical, numerical, and experimental methods. RWL and LI were calculated using a revised NIOSH lifting equation, low back compression force was predicted with the help of 3DSSPP software and muscle fatigue response was experimentally recorded using sEMG.

The following observations were made after the ergonomic redesign of the task:

(a) There was a 111.12% increase in the recommended weight limit and a 52.77% reduction in the lifting index calculated using the revised NIOSH lifting equation. The increased recommended weight limit and reduced lifting index signifies that the individual can lift a load higher than the one being lifted in the initial posture, without risk of MSDs.

(b) There was a 28.15% reduction in low back compression force calculated using the 3DSSPP software.

(c) The average back-compression force value has been brought down to 668.95 lb after the redesign, which was much lower than the Back-Compression Design Limit (BCDL) of 770 lb implying that the stresses exerted on L4/L5 were within safe limits.

(d) Analysis of muscle activity using sEMG indicated approximately 60% reduction in the slope of the voltage regression line, a 50.23% reduction in the value of peak spectral power, and a shift of peak spectral power to higher frequency. This was an indication of reduced muscular fatigue level after the redesign of the task.

From the above-mentioned findings, it can be inferred that these recommendations can be implemented in daily manual lifting tasks to avoid the high risk of muscle injuries and pain. Also, in further research, these tools, when used in combination, can be effectively applied to assess the potential risk of injuries for various lifting tasks under a wide range of work settings. For the first time, the present work reported that the change in the lifting posture according to NIOSH guidelines would delay the onset of fatigue in erector spinal muscles during manual lifting activities.

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