ORIGINAL ARTICLE

Ergonomic Evaluation of Citrus Harvest Workers' Tasks Using 3DSSPP

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Abstract

Background: As one of the important occupational groups in the field of agriculture, citrus harvest workers face various ergonomic risk factors, such as the risk of MSDs. In the present study, the 3D static strength prediction program (3DSSPP) was used to investigate MSD discomfort and evaluate biomechanical stresses. Moreover, the correlations between the biomechanical stresses and the prevalence of MSDs among citrus harvest workers were investigated.

Methods: In this cross-sectional descriptive study, 105 citrus harvest workers with at least one year of work experience participated. All job tasks were analyzed using the hierarchical task analysis (HTA) method. The Nordic musculoskeletal questionnaire (NMQ), body map, and 3DSSPP were used to collect data. The correlations of MSDs with individual characteristics and forces acting on the body were investigated.

Results: The findings showed that the highest reports of pain and discomfort were in the back region and the highest biomechanical force was applied to the L5/S1 disc during sorting, while the force distribution and balance status were appropriate in all activities. Analysis of the correlation showed that biomechanical forces, age, and work experience were among the effective risk factors of MSDs.

Conclusion: According to the results, the prevalence of MSDs was high, especially in the back and neck. The biomechanical forces on the spine and other joints in each task can be affected by the weight of the citrus boxes, the height of lifting and putting down the boxes, and the static sitting and standing postures during picking and sorting tasks.

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Introduction

Musculoskeletal disorders (MSDs) are one of the crucial occupational health concerns that can lead to partial or permanent disability as well as a reduction in the work ability index and even the workers' quality of life.[1] The causes of these disorders in various jobs have been investigated.[2] Applying excessive forces to the joints and body tissues, which mainly occurs in tasks with repetitive movement, manual load carrying, and static and awkward body postures, has been considered as one of the important factors in occupational MSDs.[3]

Agriculture is considered one of the high-risk professions in almost all countries. More than half of the workforce is engaged in this field. Musculoskeletal disorders are the most prevalent and alarming non-fatal disease among farmers.[4]

Considering the nature of farmers' work, besides awkward postures, frequent bending, and manual load carrying, the duration of work and exposure to these risk factors can also aggravate the symptoms of work-related musculoskeletal disorders (WMSDs).[5] Moreover, the high prevalence of MSDs among citrus farmers signifies the importance of prioritizing the reduction of MSDs among them.[6] Musculoskeletal injuries may occur as a result of long-term exposure to the risk factors.[7] Some studies have shown that regarding musculoskeletal injuries, applying a large force has a greater effect than long-term exposure to occupational risk factors.[8] Despite many studies on MSDs, the exact origin of WMSDs has not been identified so far.

In many studies, the maximum compression force on the lumbar intervertebral discs is considered a proper index to measure the back disorder risk.[9] Based on evidence, excessive shear and compression force on the spine or even other joints can be an important factor in developing MSDs.[10]

Many studies have reported the prevalence of MSDs among agricultural workers.[11, 12] Investigations on farmers indicate that the back, neck, and shoulders are among the body parts most exposed to musculoskeletal injuries.[13] However, it should be noted that farmers are exposed to various risk factors due to their working environments and the variety of agricultural products. Therefore, different environments and products must be individually studied. Nevertheless, only a few studies in this field have been conducted on citrus grove workers.

According to a study on farmers in Ireland, the prevalence of MSDs was reported as 37% in the back and 25% in the neck and shoulders.[14] Additionally, the researchers emphasized that awkward body postures and exertion of a high force are often the main causes of MSDs among citrus grove workers.[15, 16]

A few of the studies on farmers have performed ergonomic evaluations of the job tasks of citrus grove workers. Ncube and his colleagues evaluated the job tasks of citrus farmers using the RULA (rapid upper limb assessment) method and reported a high incidence of musculoskeletal injuries in the upper limbs. However, the RULA method and other ergonomic assessment methods are observational and do not provide accurate information on the biomechanical forces on the body.[17]

According to what was mentioned above, despite the exposure of citrus grove workers to ergonomic risk factors, only a few studies have investigated the causes of MSDs among this occupational group. Furthermore, to the best of our knowledge, no study has been conducted using biomechanical software or observational tools to more precisely investigate the biomechanical stresses on citrus workers during their tasks. A more accurate assessment of occupations can be very helpful in designing appropriate ergonomic interventions and more accurately estimating the probability of MSDs. Therefore, we decided to investigate musculoskeletal discomforts, assess the biomechanical stress on citrus grove workers using the 3D static strength prediction program (3DSSPP), Version 7.1.3, and determine the correlation between this stress and the prevalence of MSDs. The results of this study can help better understand the working conditions and design ergonomic interventions to reduce the prevalence of MSDs in this occupational group.

Methods

Participants

This is a cross-sectional descriptive study conducted on 105 citrus grove workers in the city of Jiroft, Iran, from October 2022 to February 2023. The participants of the study were selected using the census method. In this way, all the workers voluntarily entered the study based on the inclusion criteria. All participants had at least one year of work experience in citrus harvesting and provided written consent prior to the study. People who had two jobs, with the second job having MSD risk factors, and those who had MSDs due to an accident or any other reason than their job, were excluded from the study.

Data Collection Tools

Demographic Questionnaire

This questionnaire included age, weight, height, work experience, and second job.

Nordic Musculoskeletal Questionnaire

The Nordic musculoskeletal questionnaire (NMQ) examines the reported cases of MSDs among the study population for different body parts on the left and right sides separately. This questionnaire, which was developed by Kuorinka and his colleagues, is used as a part of ergonomic programs.[18] In the present study, the Persian version of NMQ, whose psychometric properties had been evaluated by Choobineh and his colleagues, was used.[19]

Hierarchical Task Analysis

Hierarchical task analysis (HTA) was introduced by Annett and Duncan in 1967.[20] This method, which describes the activity under analysis based on a hierarchy of goals, subgoals, operations, and plans, finally provides a comprehensive description of the analyzed task.[21] The HTA method is one of the most well-known task analysis methods, with more than 30 years of continuous use.[22]

3DSSPP Software

The 3DSSPP V7.1.3 software was used to investigate the forces on the back. With the capability of simulating the body postures of people during various activities, 3DSSPP is one of the most widely used computer programs in ergonomics.[23]

3DSSPP is based on over 40 years of research at the University of Michigan's Center for Ergonomics regarding the biomechanical and static strength capabilities of employees in relation to the physical demands of the work environment. This software can be used to evaluate the physical demands of a prescribed job.[9]

Procedure

In the first step of this study, all the activities of the citrus grove workers were examined, the workers were interviewed, and all tasks were observed separately. Then, all job tasks of the citrus grove workers were analyzed using the HTA method.

Figure 1: Some sample photos of the tasks of citrus grove workers (Photograph taken by the authors). (a) weeding, (b) pruning, (c) removing dry leaves, (d, e, f) picking fruit from trees, (g) preparing the fruit to be carried to the sorting site, (h, i, j) sorting and packing, and (k) manual handling and truck loading

Figure 2: Sample snapshots from the simulation and analysis of postures in the software environment

The prevalence of MSDs was investigated using NMQ. The researcher attended the participants' workplace and provided the necessary explanations; then, the questionnaires were completed by the participants. A body map was used to refer to different body parts. According to the HTA results and considering the heavy workload during citrus harvest season, awkward postures were considered for the fruit harvesting tasks such as picking the fruits from the tree, sorting/packing, and manual carrying/loading the fruits. In this way, it was possible to examine the forces on the body and investigate the body balance using the 3DSSPP software.

This process was performed for each worker who entered the study in the following manner. During the mentioned tasks, photos were taken in the worst posture, while the bending angle and position of the body parts were visible (Figure 1). Then, based on simulation in the software environment, the amount of compression and shear forces on the L_5/S_1 disc as well as the forces on other body parts were calculated; then, the body balance was examined (Figure 2).

Statistical Analysis

To analyze the data collected, we used SPSS V20. The features and characteristics of the subjects studied were analyzed using descriptive statistical methods. The correlation between the forces on the back and MSDs was determined using the independent t-test. Moreover, the correlations between individual factors and MSDs were determined using the independent t-test and chi-square test. A significance level of $P<0.05$ was considered.

Ethical Consideration

This study was approved by the Ethics Committee of Kerman University of Medical Sciences. The Ethics Code (IR.KMU.REC.1400.609) was obtained from the Research Committee of Kerman University of Medical Sciences. All procedures were performed in accordance with relevant ethical guidelines. Confidentiality of participant information was strictly observed throughout the study.

Results

Demographic Characteristics and HTA Results

A total of 105 people participated in the study. About 58% of the participants had more than 10

Table 1: Demographic/population data and their correlations with MSDs

Characteristics	n (%)/Mean ±SD
Age (years)	35.17±12.945
Height(cm)	168.26±10.731
Weight (Kg)	65.04 ±10.344
BMI	22.88±2.129
Work experience (years)	15.33±12.953
<5	27 (25.7%)
5-10	20 (19%)
≥10	58 (55.2%)
Daily working hours	7.5±2.1
Marital status	
Single	29 (27.7%)
Married	76 (72.3%)
Education level	
Illiterate	47 (44.8%)
Primary school	50(47.6%)
High school degree and above	8 (7.6%)

years of work experience, and the mean age of the participants was 35 years. The mean weight of the citrus boxes manually handled by the participants was 10 kg. Other demographic details are shown in Table 1.

The HTA results showed that the most important workers' tasks that contributed to a heavy workload include picking the fruits from the tree, sorting/packing, manual handling, and truck loading. Other details are displayed in Table 2.

Prevalence of MSDs

The results of NMQ showed that the highest frequency of MSDs over the last 12 months corresponded to the lower back and neck. Among the study population, some subjects reported more than one case of MSD during the last 12 months. Moreover, 16.6% of the workers reported MSDs in more than six anatomical regions over the last 12 months, and 19.4% of the subjects reported MSDs that had occurred simultaneously in two body regions (Figure 3).

Posture Analysis Using 3DSSPP

The output of 3DSSPP showed the highest compression force on the L_5/S_1 disc in the sorting and packing task, and the highest shear force again on the L_5/S_1 disc in the manual handling and truck loading task. The forces acting on other body parts during the four tasks are presented in Table 2.

The body balance status in all activities studied was acceptable. The percentage of the participants who were sufficiently strong to perform these tasks using the wrist, elbow, shoulder, torso, hip, knee, and ankle is presented in Table 2. The ankle and knee were the limiting body parts.

In all activities, the shear and compression forces on both L_4/L_5 and L_5/S_1 discs were respectively less than 500 N and 3400 N, which are in the safe zone (Table 3).

Correlation between Forces Acting on Body Parts and Prevalence of MSDs

The analysis results of the correlation between

Table 2: Hierarchical task analysis for citrus harvest workers

Activity	Task	Subtask
Planting	Preparation of citrus saplings	
	Digging pits with appropriate depth to plant saplings	
	Putting sapling in pit and covering its roots with soil	
	Irrigating saplings	
Cultivating	Grove irrigation	Examining irrigation equipment
		Starting the pump
	Weeding	
	Pruning	
Harvesting	Picking fruit from tree	
	Putting in boxes	
	Loading the boxes in truck	

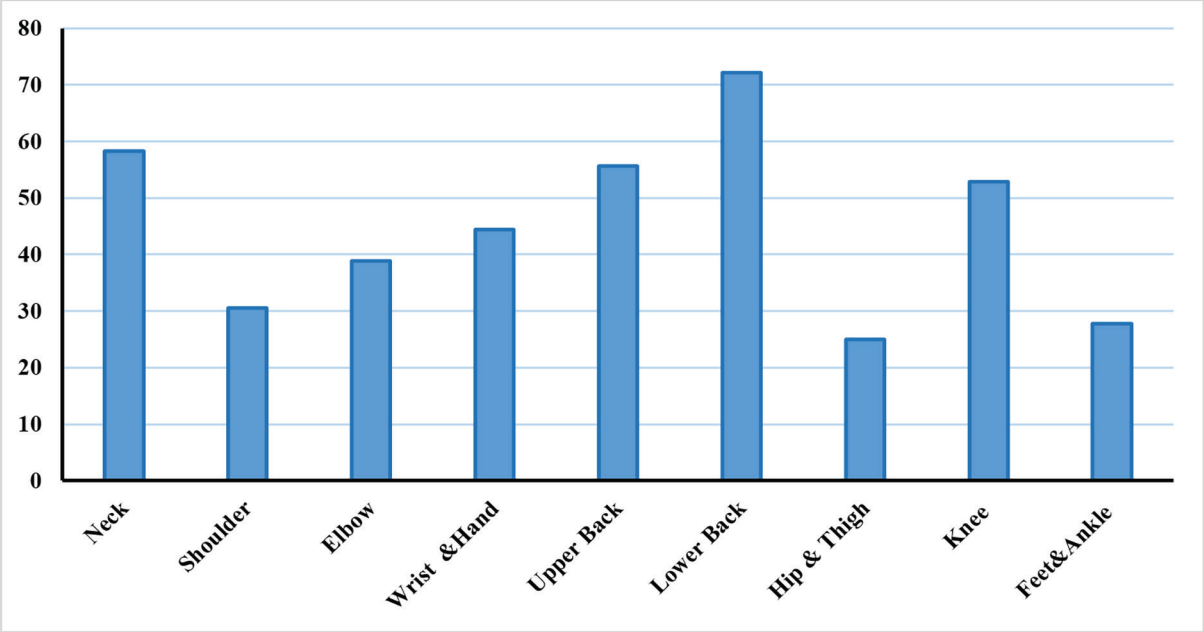

Figure 3: Bar chart of MSD frequency in nine anatomical regions of the body

Table 3: Descriptive analysis of the forces on the body parts, the percentage of the participants who can perform the task, and body balance status in three tasks

		Mean ±SD / n (%)		
		Picking	**Sorting and packing**	**Manual handling and truck loading**
A single fruit picked from tree Weight (kg)		0.25±0.02	0.25±0.02	-
Manually handled container Weight (kg)		-	-	10±1.84
3D low back analysis	Compression Forces L4/ L5	1020.7778±370.64462	1864.0833±419.200966	1617.0556±219.06671
	Shear Forces L4/ L5	137.3889±34.80827	147.1944±65.522436	114.3889±29.27922
Sagittal plane low back analysis	Compression Forces L5/S1	1034.3333±414.74316	1936.0833±449.380931	1535.9722±182.30312
	Shear Forces L5/S1	221.1389±51.69479	200.2222±64.899091	373.2222±301.40264
Joint Forces	C7/T1	-40.0528±3.98731	-52.6161±8.848314	-50.5758±9.91795
	Left Hand	-1.9333±0.60757	-.5417±0.650000	-50.0000±0
	Right Hand	-1.9333±0.60757	-1.0278±0.942220	-50.0000±0
	Left Wrist	-5.8667±0.93717	-4.4750±0.836105	-53.9556±0.62812
	Right Wrist	-5.8667±0.93717	-4.0056±3.164711	-53.9556±0.62812
	Left Elbow	-16.9056±2.52710	-15.5139±2.401803	-66.4778±9.08107
	Right Elbow	-16.9056±2.52710	-16.0000±2.516574	-61.5278±21.33915
	Left Shoulder	-35.2278±5.40569	-33.8500±5.282829	-106.6750±142.08688
	Right Shoulder	-35.2278±5.40569	-34.3361±5.34464	-83.3000±5.30504
	Left Hip	-192.6528±52.32584	-212.1556±79.54693	-347.4722±56.65743
	Right Hip	-211.9694±50.82169	-172.3167±67.61016	-156.4167±52.73556
	Left Knee	-273.2278±60.20531	-288.8861±108.67874	-404.7667±151.24944
	Right Knee	-295.8417±59.99058	-234.8111±128.16255	-219.6333±117.65906
	Left Ankle	-300.9722±64.45017	-317.4694±119.04291	-427.2639±173.58953
	Right Ankle	-272.3778±187.18847	-265.3500±134.00510	-264.6806±63.77420
Percent Capable	Wrist	99.0±0	99.0000±0	96.4444±0.87650
	Elbow	100.0±0	100.0000±0	99.0278±0.16667
	Shoulder	99.5278±0.50631	99.7778±0 .42164	97.6111±1.93136
	Torso	98.6667±0.58554	98.7222±1.03126	96.7222±2.47976
	Hip	97.7222±0.91374	96.0833±1.96214	90.0833±3.95962
	Knee	98.9167±0.28031	69.6389±34.70048	84.8611±9.92875
	Ankle	98.2500±0.90633	98.9444±0 .33333	87.8333±13.15077
Balance	Acceptable	105(100%)	105(100%)	105(100%)
	Critical	0	0	0

individual factors and MSDs based on an independent t-test and chi-square statistical test with a significance level of $P<0.05$ were obtained. These results showed significant correlations between age and work experience with pain in the upper and lower back anatomical regions over the last 12 months (Table 4).

The correlations between the forces on the body parts and the prevalence of MSDs in each of the corresponding body parts during the three studied tasks were obtained. The results showed that, in manual handling and truck loading postures, there was a significant correlation between the prevalence of MSDs in the right foot/ankle and the force on this joint (Table 5).

Discussion

To the best of our knowledge, the present study is the first research that estimates the forces exerted on the body parts of citrus harvest workers and evaluates the correlation between these forces and MSDs in this occupational group. Based on the results of HTA and time analysis of the tasks performed by the studied workers, the longest working time intervals were related to three harvest activities, including citrus picking, sorting/packing, and manual handling/truck loading.

Additionally, investigations showed a very high prevalence of MSDs among citrus harvest workers, with the highest prevalence in the back (72.2%). These results agree with the findings of the studies on Iranian and Korean agricultural workers.[13, 24, 25] The activities of citrus harvest workers include manual and postural tasks, which require inevitable force exertion and awkward postures, such as bending, twisting, stretching of the limbs, and static postures. Therefore, the obtained results in terms of the high prevalence of MSDs were expected.

Analysis of Working Postures Using 3DSSPP

In the present study, the forces acting on the body parts in the three main tasks of citrus harvest were estimated using 3DSSPP. The results showed that the highest compression and shear forces applied to the L_5/S_1 disc of the workers occurred during the task of sorting/packing. However, in all tasks, the amounts of compression and shear forces on the L_5/S_1 and L_4/L_5 discs were in the safe zone.

Table 4: Correlation between demographic characteristics and MSDs

GROUP	Age		Height		Weight		BMI		Work Experience		Marital status		Education level	
	T statistic	P-Value	T statistic	P-Value	T statistic	P-Value	T statistic	P-Value	T statistic	P-Value	chi-square	P-Value	chi-square	P-Value
Upper Back (NO)	-2.171	.037*	-.813	.422	-.306	.762	.458	.651	-2.543	.016*	.173	.677	2.225	.329
Upper Back (YES)														
Lower Back (NO)	-4.246	.000*	-1.063	.295	-.970	.339	.377	.709	-4.378	.000*	.418	.518	2.934	.231
Lower Back (YES)														
Neck (NO)	.013	.990	.915	.367	-.469	.642	-2.130	.041	-.154	.878	.016	.900	2.602	.272
Neck (YES)														
Wrist & Hand (NO)	.843	.405	-.335	.740	.402	.690	1.157	.255	1.456	.155	1.170	.279	4.925	.085
Wrist & Hand (YES)														
Elbow (NO)	.744	.462	.716	.479	.244	.809	-.495	.623	.859	.396	.007	.932	2.400	.301
Elbow (YES)														
Shoulder (NO)	-.391	.698	-.005	.996	.779	.442	1.353	.185	-.230	.820	2.757	.097	.424	.809
Shoulder (YES)														
Hip & Thigh (NO)	-.161	.873	-.882	.384	-.393	.697	.657	.516	-.117	.907	.185	.667	4.706	.095
Hip & Thigh (YES)														
Knee (NO)	-1.893	.067	.295	.770	1.114	.273	1.441	.163	-1.916	.064	1.648	.199	1.285	.526
Knee (YES)														
Foot & Ankle (NO)	-.180	.859	.363	.719	.619	.540	.519	.607	-.132	.896	2.181	.140	.130	.937
Foot & Ankle (YES)														

Table 5: Prevalence of MSDs and the significance of the associations between MSDs and forces acting on different body parts in citrus harvesting tasks

Body parts	GROUP	Picking fruit			Sorting and packing			Manual handling and truck loading		
		Mean of Force ±SD	T statistic	P value	Mean of Force ±SD	T statistic	P value	Mean of Force ±SD	T statistic	P value
Compression Forces at L_4/L_5	Upper Back (NO)	981.8750±354.34933	-0.558	0.581	1919.5000±485.76400	0.704	0.486	1608.0625±200.71289	-2.17	0.829
	Upper Back (YES)	1051.9000±389.41061			1819.7500±364.37298			1624.2500±237.64677		
Shear Forces at L_4/L_5	Upper Back (NO)	134.3750±35.42857	-0.459	0.649	160.2500±75.11103	1.072	0.291	113.4375±32.44682	-172	0.865
	Upper Back (YES)	139.8000±35.03171			136.7500±56.53492			115.1500±27.32509		
Compression Forces at L_4/L_5	Lower Back (NO)	848.0000±332.52469	-1.788	0.083	1749.5000±160.17993	-1.486	0.146	1539.7000±157.22881	-1.328	0.193
	Lower Back (YES)	1087.2308±368.76652			1908.1538±479.07500			1646.8077±234.46245		
Shear Forces at L_4/L_5	Lower Back (NO)	122.3000±32.22163	-1.652	0.108	140.8000±60.20668	-0.359	0.722	119.1000±23.68989	0.593	0.557
	Lower Back (YES)	143.1923±34.58904			149.6538±68.43154			112.5769±31.39831		
Compression Forces at L_5/S_1	Upper Back (NO)	984.5000±391.43429	-0.639	0.527	2005.2500±525.99284	0.822	0.417	1519.2500±174.24446	-0.487	0.629
	Upper Back (YES)	1074.2000±438.33316			1880.7500±382.52662			1549.3500±191.90658		
Shear Forces at L_5/S_1	Upper Back (NO)	223.7500±42.75278	0.267	0.791	208.6250±80.18219	0.690	0.495	443.6875±384.38934	1.188	0.247
	Upper Back (YES)	219.0500±58.90177			193.5000±50.75483			316.8500±207.76943		
Compression Forces at L_5/S_1	Lower Back (NO)	845.1000±376.85200	-1.747	0.09	1815.0000±186.16719	-1.44	0.159	1474.3000±99.65836	-1.686	0.102
	Lower Back (YES)	1107.1154±412.13778			1982.6538±511.98000			1559.6923±202.10448		

Body parts	GROUP	Picking fruit			Sorting and packing			Manual handling and truck loading		
		Mean of Force ±SD	T statistic	P value	Mean of Force ±SD	T statistic	P value	Mean of Force ±SD	T statistic	P value
Shear Forces at L_5/S_1	Lower Back (NO)	213.9000±27.23743	-0.516	0.609	193.3000±56.79016	-0.392	0.697	354.1000±294.36238	-0.233	0.817
	Lower Back (YES)	223.9231±58.69577			202.8846±68.62264			380.5769±309.49109		
C_7/T_1	Neck (NO)	-39.7527±3.61475	0.377	0.709	-52.8800±9.01586	-1.49	0.882	-50.7567±9.563792	-0.091	0.928
	Neck (YES)	-40.2671±4.30817			-52.4276±8.94554			-50.4467±10.395749		
Left Hand	Left Wrist & Hand (NO)	-1.9000±0.61559	0.363	0.719	-0.7150±.66354	-1.878	0.069	-50.5350±1.31880	-0.346	0.732
	Left Wrist & Hand (YES)	-1.9750±0.61482			-0.3250±.58138			-50.3938±1.07732		
Right Hand	Right Wrist & Hand (NO)	-1.9000±0.61559	0.363	0.719	-1.2150±.8604	-1.348	0.186	-50.1650±0.73790	1.641	0.116
	Right Wrist & Hand (YES)	-1.9750±0.61482			-0.7938±1.01421			-50.8562±1.55004		
Left Wrist	Left Wrist & Hand (NO)	-5.8700±0.93758	-0.024	0.981	-4.6850±.79490	-1.732	0.092	-53.9950±0.60042	-0.416	0.680
	Left Wrist & Hand (YES)	-5.8625±0.96738			-4.2125±.83576			-53.9063±0.67771		
Right Wrist	Right Wrist & Hand (NO)	-5.8700±0.93758	-0.024	0.981	-4.0350±3.51213	-0.62	0.951	-53.9950±0.60042	-0.416	0.680
	Right Wrist & Hand (YES)	-5.8625±0.96738			-3.9688±2.78250			-53.9063±0.67771		
Left Elbow	Left Elbow (NO)	-17.1273±2.15057	-0.654	0.517	-15.5273±2.14769	-0.041	0.967	-65.0636±2.05763	0.941	0.364
	Left Elbow (YES)	-16.5571±3.08363			-15.4929±2.84239			-68.7000±14.36947		
Right Elbow	Right Elbow (NO)	-17.1273±2.15057	-0.654	0.517	-15.9818±2.09617	0.054	0.958	-65.0636±2.05763	-0.996	0.337
	Right Elbow (YES)	-16.5571±3.08363			-16.0286±3.15459			-55.9714±34.12803		
Left Shoulder	Left Shoulder (NO)	-35.5360±5.44257	-0.51	0.613	-34.4040±5.25266	-0.947	0.350	-117.4200±170.40151	-0.679	0.502
	Left Shoulder (YES)	-34.5273±5.51418			-32.5909±5.38060			-82.2545±5.26581		
Right Shoulder	Right Shoulder (NO)	-35.5360±5.44257	-0.51	0.613	-34.9040±5.49837	-0.960	0.344	-83.7600±5.36353	-0.780	0.441
	Right Shoulder (YES)	-34.5273±5.51418			-33.0455±4.97823			-82.2545±5.26581		
Left Hip	Left Hip & Thigh (NO)	-190.1667±50.94185	0.488	0.628	-209.1000±90.50215	0.394	0.696	-342.3370±56.88108	0.940	0.354
	Left Hip & Thigh (YES)	-200.1111±58.83278			-221.3222±30.62890			-362.8778±56.32761		
Right Hip	Right Hip & Thigh (NO)	-214.7926±55.39148	-0.572	0.571	-166.2296±76.12602	0.934	0.357	-159.2593±55.29470	0.555	0.583
	Right Hip & Thigh (YES)	-203.5000±34.93769			-190.5778±25.77216			-147.8889±46.05511		
Left Knee	Left Knee (NO)	-290.1647±59.70791	-1.634	0.111	-314.8765±57.50030	-1.374	0.178	-398.5235±214.04409	0.231	0.819
	Left Knee (YES)	-258.0737±58.01500			-265.6316±137.17966			-410.3526±60.72725		
Right Knee	Right Knee (NO)	-296.4706±68.41751	-0.059	0.954	-269.7882±48.80388	-1.582	0.123	-241.1059±72.78840	-1.037	0.307
	Right Knee (YES)	-295.2789±53.25640			-203.5158±166.22975			-200.4211±146.23158		
Left Ankle	Left Foot & Ankle (NO)	-295.2423±61.94208	0.857	0.398	-311.6462±136.32072	0.468	0.643	-407.1538±197.58657	1.125	0.268
	Left Foot & Ankle (YES)	-315.8700±71.79465			-332.6100±56.01090			-479.5500±67.33159		
Right Ankle	Right Foot & Ankle (NO)	-289.5500±184.33926	-0.885	0.382	-275.7846±121.81811	-0.749	0.459	-280.3808±63.49607	-2.564	0.015*
	Right Foot & Ankle (YES)	-227.7300±196.99353			-238.2200±165.77269			-223.8600±45.31905		

* Correlation was significant at a level of 0.05.

As observed, in the three studied tasks, the lowest forces were related to the upper limbs, especially the hands and wrists, and the highest forces were related to the lower limbs. The body balance was acceptable in all tasks. In the sorting and manual handling tasks, the ankle and knee were the limiting parts, such that in only less than 30% of the workers, performing these tasks was considered safe for the seven main body parts.

In a study, Hassani et al. showed that back pain was very high among sugar production workers during fertilizer transportation. Based on the results of 3DSSPP, the maximum compression and shear forces on the L_5/S_1 disk of the workers were estimated to be 7113 N and 472 N, respectively.[26] In another study on banknote printing process workers using 3DSSPP, the authors estimated the compression force on the L_5/S_1 disk to be between 1072 N and 1863 N and the amount of shear force on this region to be between 263 N and 310 N.[27] In a study on waste collection workers, Silvetti et al. used 3DSSPP and found an unacceptable balance in many tasks.[28] Some studies on biomechanical forces in manual load-carrying tasks using 3DSSPP have reported the risk of biomechanical overload and back injury. For example, the results of a study by Beyrami et al. on young block-making workers showed that the shear forces exerted on the lower back of the participants were 30-37% higher than the permissible limit, and on average, 42.5% of them experienced compression forces. Therefore, manual load carrying is risky in the studied age group in this occupational category. Accordingly, these workers may suffer serious injuries and disorders, especially in the lower back region.[29]

In other similar studies among similar occupational groups, the weight of the load, the height of lifting or putting down the load, awkward postures, and the type of task are the most important MSD risk factors.[30, 31] In the citrus harvest workers' tasks, the weight of the citrus boxes, the height of lifting or putting down the boxes, and bending/twisting along with stretching of the body to perform sorting and picking tasks are among the ergonomic risk factors that are usually inevitable. However, in many studies, these risk factors have been considered harmful to the spine, especially in the lower back region.[32] Biomechanical factors, including posture and applied forces, as well as the time sequence of these two factors, are strongly related to the development of MSDs. Both posture and applied force exert a mechanical load on the lumbar spine, so the risk of MSDs in this region[33] is increased. Studies have shown that the best strategy to prevent MSDs is to maintain a musculoskeletal load that is appropriate for work-related tasks.[34]

Correlation between Forces on Body Parts and Prevalence of MSDs

Excessive load on the musculoskeletal system during work-related tasks is a very important factor that often leads to MSDs. In the present study, the correlation between the forces on body parts and the prevalence of MSDs among citrus harvest workers was investigated. In agreement with previous studies in this field,[31, 35] in manual handling and truck-loading tasks, the force exerted on the ankle joint had a significant correlation with the prevalence of MSDs over the last 12 months. However, it is interesting that the correlation between the forces on different body parts and the prevalence of MSDs in them was not significant in other tasks. Meanwhile, high prevalence rates of MSDs among workers were reported for some body parts such as the back (72.2%) and neck (58.3%). These results indicate that although the forces applied to some body parts of these workers are not strong during working postures (i.e., these forces are in the no-risk range), the workers maintain a posture for a long time in many of the tasks. Grandjean suggested that the maximum holding time for a static posture can be defined in three levels according to the amount of force required to hold the posture. Accordingly, for a large force, the recommended maximum holding time of the corresponding posture is 10 seconds, for a medium force, it is less than one minute, and for a small force, it is less than four minutes.[36]

Workers' awkward work postures are maintained or repeated for a prolonged time in tasks such as picking fruits and sorting them. Therefore, it is suggested that future studies should investigate the maximum holding time (MHT) in different postures in the tasks of citrus grove workers and compare the findings with the existing ergonomic recommendations.[37] In many studies, some factors such as individual characteristics, psychosocial factors of the work environment,[38, 39] tool ergonomics,[40] and personal protective equipment are also known to be effective in the onset or aggravation of MSDs. However, in the case of citrus grove workers, the elimination of the biomechanical stresses resulting from work tasks may be recommended as the first necessary measure to reduce the risk level.

In general, the results of the present study show the need for implementing an ergonomic intervention program, which includes improving working postures (considering MHT of the postures), training the correct principles of manual load carrying/handling, and providing corrective exercises with a focus on the back position, especially for the tasks of citrus harvest workers to reduce MSDs among them and maintain their health. Additionally, it seems necessary to design and develop tools that can eliminate some high-risk tasks or reduce the amount of harm in this occupational group.

Limitations

In the present study, other effective factors in the occurrence of MSDs, such as the musculoskeletal structure of participants, psychosocial factors of the work environment, and the use of tools by the workers, were not considered although each of these factors can cause or aggravate MSDs. It is suggested that these factors, along with biomechanical stresses, might be investigated in future studies.

Conclusion

The 3DSSPP analysis results for the three tasks of fruit picking, sorting/packing, and manual handling/truck loading showed that the highest biomechanical forces were exerted on the L_4/L_5 and L_5/S_1 spinal discs during the sorting/packing task. These forces depend on the weight of citrus containers and boxes, the height of lifting and putting down the boxes, static postures, and the simultaneous stretching and twisting of the body. The correlations between the studied variables were analyzed, and the results showed that the forces on the joints as well as the individual factors of age and work experience were among the risk factors affecting MSDs. It is worth mentioning that the correlations between the forces exerted on different body parts and the prevalence of MSDs in them were not significant in some tasks. This indicates that the force exerted on some body parts in the working postures of the citrus harvest workers is not high and remains within the no-risk range. However, in some tasks, these workers hold a posture for a long time. Therefore, it is suggested that further analysis of the data related to MHT and fatigue due to the repetitive picking and packing tasks performed by citrus harvest workers should be done.

Authors' Contributions

MA and ZZ contributed to the study conceptualization and preliminary study design. HM, AH, and FM performed field assessments and were responsible for data collection. SS guided the study design, oversaw data analysis. MA drafted the initial manuscript, and SS provided substantial revisions. All authors reviewed and approved the final version of the manuscript.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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