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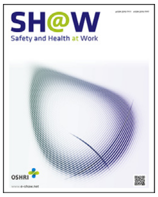

Original Article

The Effects of Ramp Gradients and Pushing–Pulling Techniques on Lumbar Spinal Load in Healthy Workers

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ABSTRACT

Background: Many tasks in industrial and health care setting are involved with pushing and pulling tasks up or down on a ramp. An efficient method of moving cart which reduces the risk of low back pain should be concerned. This study aimed to investigate the effects of handling types (HTs) and slope on lumbar spinal load during moving a cart on a ramp. We conducted a $2 \times 2 \times 4$ factorial design with three main factors: 2 HTs, 2 handling directions of moving a cart and 4 degrees of ramp slope.
Methods: Thirty healthy male workers performed 14 tasks consist of moving a cart up and down on the ramp of 0°, 10°, 15°, and 20° degrees with pushing and pulling methods. Joint angles from a 3D motion capture system combined with subject height, body weight, and hand forces were used to calculate the spinal load by the 3DSSPP program.
Results: Our results showed significant effect of HT, handling directions and slope on compression and shear force of the lumbar spine ($p < 0.001$). When the ramp gradient increased, the L4/5 compression forces increased in both pushing and pulling ($p < 0.001$) Shear forces increased in pulling and decreased in pushing in all tasks. At high slopes, pulling generated more compression and shear forces than that of pushing ($p < 0.01$).
Conclusion: Using the appropriate technique of moving a cart on the ramp can reduce the risk of high spinal load, and the pushing is therefore recommended for moving a cart up/down on ramp gradients.

1. Introduction

In accordance with the National Institute for Occupational Safety and Health, more than 500,000 workers developed a musculoskeletal disorder as a result of manual material handling (MMH) tasks [1,2]. MMH consists of tasks such as: lifting, pushing, pulling, lowering and carrying. Thus, performing MMH tasks is considered to be one of the major risk factors for work-related musculoskeletal disorders. The combination of high physical work-loads and MMH is generally regarded to be a primary factor in work-related musculoskeletal disorders, e.g., low back and shoulder complaints [3]. Studies of the effects of lifting on health complaints were widely emphasized in ergonomic fields [4]. However, pushing and pulling tasks which are 50% of MMH are scarcely studied [5,6].

Many occupations involve pushing and pulling tasks, for instance, workers in industries, workers in hospitals who move wheelchairs or beds, flight attendants and several services such as shipping and receiving, transporting, warehousing, garbage collecting, farming, firefighting, and construction. Epidemiological investigations reported that 9 to 18% of low back complaints or injuries are related to pushing and pulling [7–12]. Many previous studies have shown that pulling and pushing work is associated with musculoskeletal injuries, especially in industry [13–17]. Related studies on biomechanics have shown changes in the body that may result in injury while pushing and pulling objects. Although pushing, mechanical stress occurs on the joints of the

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body such as increased shear force on the lumbosacral joint and loads on the shoulder complex both the glenohumeral joint and acromioclavicular joint [18]. The increase in muscle activities, especially in the torso muscles was found while performing pushing and pulling [19,20]. In addition, the changes in posture or curvature of the lumbar spine such as the trunk leaning forward or leaning back are biomechanic changes that can be found during pushing and pulling [9,19]. Those trunk muscle activities and postural changes are risk factors in MMH tasks, which are related to low back pain involving high level spinal compression and shear forces [21]. These high level spinal forces can be produced by exertion forces of MMH and postures of the workers. Therefore, many researchers have attempted to investigate spine compression forces when performing pushing and pulling tasks [19,21–23]. In addition, a biomechanical model in the form of a computer program to calculate compression and shear forces from workers' postures and hand forces or 3D Static Strength Prediction Program (3DSSPP) have been developed [24]. This program was used in ergonomic fields and many research studies [25–29].

Furthermore, recent research has also studied factors influencing pushing and pulling tasks. These factors include speed of motion, load conditions, psychophysiological, force orientations, load magnitudes, work experience, hand force limits, handle height, interhandle distance, ramp gradients, and direction of exertion. In addition these are risk factors of work-related injuries [12,30–39]. Many tasks in industrial and health-care settings are associated with pushing and pulling [9]. Particularly, pushing or pulling a cart up or down a ramp is often found in factories and hospitals. Those ramps are between 4 and 10°, especially in industries where ramps can be up to 15 to 20°. Moreover, two common ways to move a cart up and down a ramp are pushing and pulling. However, no research studies have compared the biomechanic factors particularly spinal load between those two common methods of moving a cart on a ramp.

As aforementioned, compression and shear forces, at the lumbar spine when pushing and pulling a cart, vary depending on posture and degree of slope whether pushing or pulling is performed. As a result, these factors may lead to low back injury. Therefore, the study aimed to investigate the effects of pushing and pulling a moving cart in up and down directions and various slope degrees of a ramp on lumbar spinal load among workers. We hypothesized that lumbar spinal load differences would be presented in all manual handling conditions. Compression and shear forces, on the spine while moving a cart up and down a slope, were investigated using different techniques. These findings can be used to consider the appropriate techniques to reduce the work-related injuries caused by excessive spinal loads.

2. Materials and methods

This study used a cross-sectional 2 × 2 × 4 factorial design representing two handling types (HTs) (push forward and pull backward), handling direction (HD) (move the cart up and down) and four degrees of ramp slope (0°, 10°, 15°, and 20°). The test was conducted and simulated in a motion analysis laboratory at the Faculty of Physical Therapy, Mahidol University Thailand. Healthy male workers working in industrial settings or hospitals in Bangkok Metropolitan Region were invited to participate in this study. They were included if they (a) had age ranging from 20 to 59 years, (b) usually performed pushing or pulling tasks for 1 hour/day, 4 days a week and had at least 2 years' working experience in pulling and pushing objects on a ramp, and (c) had no complaint of musculoskeletal disorders within 7 days measured by the modified Nordic questionnaire [40]. Participants who reported cardiopulmonary complications, neurological problems or history of bone and muscular surgery within 3 years that affected pushing or pulling tasks were excluded.

This studys' protocol was approved by Mahidol University Institutional Review Board (COA No. MU-CIRB 2017/047.1603) before collecting data.

2.1. Simulation workstation

The simulation workstation consisted of a simulation walkway and cart (Fig. 1) made from smart board 1.2 m wide, 4.8 m long (2.4 m flat part and 2.4 m slope part), and thickness of 1.2 cm. The ramp gradients could be adjusted to 10°, 15°, and 20° from the horizontal plane. All floor surfaces of the slope part were covered with nonslip material to prevent slipping. The end of the flat part and the side of the walkway had barriers to prevent the cart from moving out of the walkway. The study used a fixed four-wheeled cart with a deck 0.48 m wide, 0.74 m long with a height adjustable handle (Fig. 1). To determine the cart weight, pushing force at 22 kg was chosen based on the acceptable exertion from a Snook and Ciriello [12] table. A pushing force at the handle of the cart at a 20-degree ramp was measured by a dynamometer (Lafayette model 01165, United States). During the measurement, the weight of the cart was increased by putting sand weights until the pushing force reached 22 kg. The cart weight was then determined by a scale (Progress RCS-200, China), and it was found to be around 40 kg.

2.2. Spinal load determinations

The main types of forces in the spine affecting any injury of the lower back are compression and shear forces. The lumbar spine (L4/5) compression and shear forces were calculated by entering absolute joint angles of the body in the 3DSSPP Software, version 6.0.6. The absolute joint angles were determined using the Vicon™ Motion Analysis System (Oxford Metrics Ltd., Oxford, UK). This system consisted of eight video cameras, calibration kits, workstation PC with Windows Software, and 35 reflective spherical markers with 1.4 cm diameter. The Vicon™ Software was used to record body motion when testing and reported each marker

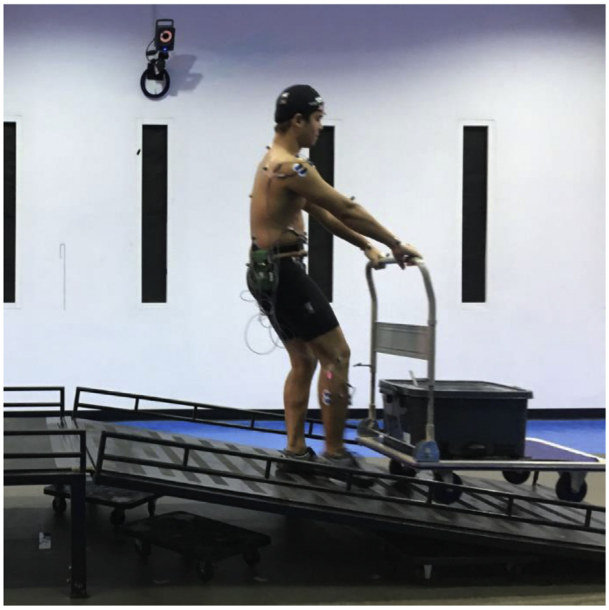


Fig. 1. Participant posture during moving a cart on a ramp.

location in horizontal and vertical axes. The MATLAB program was used to convert the marker locations to absolute joint angles.

2.3. Procedure

The research procedure was described to all eligible participants who passed the inclusion and exclusion criteria. Included participants were asked to sign a consent form before collecting data. Their personal information was recorded including age, weight, height, education level, occupation, and working experience.

Individuals were asked to wear a nonreflective black sleeveless shirt, short pants, and shoes during the test. The same type of shoes was applied to control the confounding factor from effects of friction between shoes and the floor. Then the anthropometric of all participants including hand thickness, height, body weight, leg length, and joint width of elbow, wrist, knee, and ankle were collected to analyze the 3D motion capture system followed by individuals' measurements for the Plug-in-Gait full body model [41]. The 35 spherical reflective markers were placed on the participant's body following the Plug-in-Gait Model for the Vicon™ 3D Motion Analysis System. The handle height of the cart was adjusted at waist level of each participant. The waist level was chosen because the previous study showed that the lumbar compression force is high compared with that of the shoulder level, which increases the risk of injuries [19]. All participants were instructed to practice pushing and pulling the cart on both flat and different slopes of ramp floors for 15 minutes.

The tasks consisted of evaluating two HTs to move the cart up and down (HD) on different slopes of the ramp. They were asked to perform 14 pushing and pulling tasks consisting of pushing forward and pulling backward a cart at 0° of slope (2 tasks), and moving a cart up using push-up forward (PsUF) and pull-up backward (PlUB) methods on 10, 15, and 20° degree ramps (6 tasks), and move a cart down with pull down forward (PlDF) and push down backward (PsDB) method on the 10, 15, and 20° ramps (6 tasks). The sequence of tests started with pushing and pulling on a flat floor at 0°. Then the order of testing among ramps and tasks were random. The participants completed all tasks in the same degree of the ramp before changing to perform another degree. A 5-minute was provided between tasks [42,43]. They were instructed to move the cart at their preferred speed and posture, continuously moving the cart on the ramp without stopping, and moving the cart with two hands as shown in Fig. 1.

The Vicon™ 3D Motion Analysis System recorded 35 reflective spherical markers while pushing and pulling the cart (Fig. 2). A camera frame taken of the mid-swing phase of the dominant leg when pushing and pulling on the ramp was selected to analyze the processes. The results of the X, Y, and Z axes locations of the reflective spherical markers, generated from the motion analysis system, were converted to absolute joint angle using MATLAB software. After that, the participants' anthropometry, absolute joint angles, and loads at both hands were calculated and entered in the 3DSSPP. However, this study assumed no body movement in the coronal and transverse planes; therefore, only the sagittal plane was added to the 3DSSPP Program. Then the L4/5 compression and shear forces of each pushing and pulling task were calculated using body angles and hand loads.

2.4. Data analysis

The sample size of this study ($n = 30$) was determined in accordance with that of Lett KK and McGill SM [19]. The SPSS for Windows Program, version 19 was used to analyze the statistics. Dependent variables (DVs) of the L4/5 compression and shear forces were described using mean and standard deviation. Three independent variables were HTs (push and pull), HD to move the cart (up and down) and among four degrees of ramp slope (0°, 10°, 15°, and 20°). Therefore, to study the effects of all those 3 variables, the $2 \times 2 \times 4$ factorial design was applied in this study. Normality distribution was assumed by the Kolmogorov–Smirnov goodness-of-fit test. Homogeneity of variance was assumed among the three independent variables using the Levene's test. The three-way repeated measures analysis of variance (ANOVA) was used to determine the main and interaction effects of three factors on lumbar spine load (L4/5). For main effect comparison, the DVs were compared between two HTs, two HDs, and four degrees of ramp slope (slope). For interaction effect comparison, the DVs were compared among HT x HD, slope*HT, slope*HD and slope*HT*HD. For multiple comparison, the Bonferroni correction was used to compare the compression and shear forces between each pair of HT when moving a cart up or down on various degrees of ramp slope. The significance level was set as p-value <0.05.

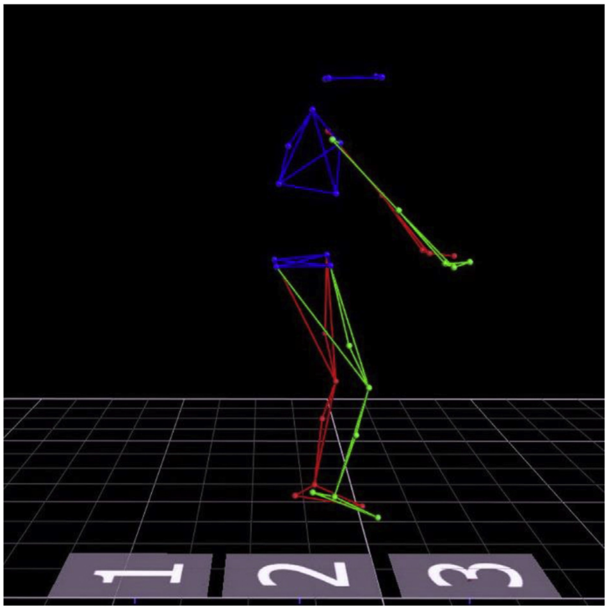


Fig. 2. Stick figure of Vicon™ motion analysis system during move a cart.

3. Results

Thirty healthy male workers volunteered to participate in this study. Their ages ranged from 23 to 55 years. In total, 26 (86.67%) participants were hospital workers and 14 (13.33%) were industrial workers. Many participants ($n = 27$) graduated from senior high school. Table 1 shows demographics of all male participants. All participants performed 14 tasks starting with moving a cart by pushing forward and pulling backward on a 0° slope (2 tasks) and followed by the task of moving a cart up with PsUF and PlUB on 10, 15, and 20° slopes (6 tasks), and moving a cart down with PlDF and PsDB on 10, 15, and 20° slopes (6 tasks).

Table 2 indicates main and interaction effects HTs (push and pull), HDs (up and down), and degree of ramp slope (0, 10, 15, and 20°) on lumbar compression and shear forces. For the main effect comparison, a significant difference of compression and shear forces among two HTs, two HDs, and four degrees of ramp slope were observed ($p < 0.001$). Significant differences were found for interaction effects in all pairs of factors (slope * HT, HT * HD and slope * HT*HD) except slope * HD of compression and shear forces (p-value $= 0.068$ and 0.144).

Table 1
Demographic characteristics of male participants (n = 30)

Characteristics	Mean ± sd	Min–max
Age (y)	36.4 ± 9.0	23.0-55.0
Weight (kg)	69.5 ± 8.3	54.5-90.0
Height (cm)	171.9 ± 6.7	160.0-190.0
BMI (kg/m^2)	23.5 ± 1.9	18.6-25.0
Anthropometry (cm.)		
Right Side		
Hand thickness	2.72 ± 0.43	1.9-3.5
Leg length	82.44 ± 6.87	70-98
Joint width		
Elbow	10.7 ± 1.3	9.5-12.4
Wrist	6.8 ± 1.46	6.4-7.1
Knee	10.85 ± 1.56	9.4-12.5
Ankle	6.5 ± 1.1	5.6-6.9
Left side		
Hand thickness	2.71 ± 0.43	1.9-3.5
Leg length	82.5 ± 6.87	70-98
Joint width		
Elbow	10.4 ± 1.3	9.5-12.4
Wrist	6.8 ± 1.46	6.4-7.1
Knee	10.73 ± 1.55	9.4-12.5
Ankle	6.5 ± 1.1	5.6-6.9
Working experience (y)	9.50 ± 8.0	2-30

Table 3 shows the effects of HTs, moving a cart in HDs and degrees of ramp slope on compression and shear forces L4/5 among workers. For the compression force, the lumbar spine load was 638.0 ± 147.0 N for moving a cart up with PsUF and moving a cart down with PsDB on a 0° slope, and 637.1 ± 139.7 N for moving a cart up with PlUB and moving a cart down with PlDF on a 0° slope. The compression force increased when slopes of the ramp were raised in each task ($p < 0.001$). A significant difference of compression force was observed between two handling methods when moving a cart up and down ($p < 0.05$).

For the shear force, the lumbar spine load was 127.9 ± 17.1 N for moving a cart by pushing forward and 165.2 ± 17.6 N for moving a cart by pulling backward on a 0° slope. The results demonstrated significant differences when moving a cart by push and pull methods on a 0° slope ($p < 0.001$). The shear force also increased when the slope of the ramp was increased only in pulling ($p < 0.01$). Regarding the pushing method, the shear force decreased when the ramp was raised ($p < 0.001$). A significant difference of shear force was observed between two handling methods when moving a cart up and down ($p < 0.001$). For the multiple comparisons (Figs. 3 and 4) statistically significant differences in all tasks were found ($p < 0.05$).

4. Discussion

Our findings demonstrated the effects of HTs and slope increment on spinal loading while pushing or pulling the four-wheeled hand cart on 10, 15, and 20° walkway gradients. The ramp gradient of 10 and 15° were investigated in many pushing and pulling research studies, whereas the angle of 20° was observed in actual situations especially in industrial settings [18,23]. The University of Michigan's 3DSSPP software was used to determine compression and shear force on L4/L5. The cart was fixed in a straight position parallel to the cart path to control direction when moving in a straight line. Therefore, this study assumed that no spine movement occurred in the transverse plane (twisting force) when moving the cart. Only compression and shear forces were investigated.

The results of this study revealed that slope of the ramp and HT affected spinal load in both compression and shear forces. Concerning the effect of slope, the compression force significantly increased when the slope of the ramp increased. This was found in both moving up and down, as well as both handling techniques. The significant increase of compression force when slope increased may have been due to two main factors. First, the body angle alteration resulted from pushing and pulling strategies when moving the cart. As the cart was moved on a low slope degree of the ramp, the participant uses the force from the upper extremity muscles to overcome gravitational and friction forces. However, when participants performed exertion on a high degree of slope, they shifted to use the muscles of the torso and legs instead of the upper extremity muscles. The alteration and increase in muscle activities, especially those of the torso muscle, will directly affect the spinal load. Second, the effect of gravity on the cart load, and the increase of the gravitational effect by the increment of slope caused external vertical load increase. Consequently, those external forces were transferred to the spine, whereas a lower gravitational effect of load was found while pushing or pulling on a flat floor. Participants used less muscle force to move the cart when compared with on the ramp. The wheels could overcome or help reduce the inertia force produced by friction. When the angle of the ramp increased, the gravitational force increased, so participants needed to produce a higher pushing or pulling force to move the cart. In addition, the

Table 2
Main and interaction effects of handling types, handling directions, and degree of ramp slope on lumbar spine load (L4/5) in healthy workers

Variables		Lumbar spine load (L4/5)			
		Compression force (Newton)		Shear force (Newton)	
		Mean ± SD	*p-value*	Mean ± SD	*p-value*
Main effect					
Slope (degrees)	0	638.0 ± 12.9	<0.001**	146.6 ± 25.4	<0.001**
	10	1010.9 ± 26.1		150.5 ± 52.7	
	15	1171.7 ± 32.9		154.2 ± 70.3	
	20	1439.4 ± 46.9		168.2 ± 96.3	
Handling Type	Push	1022.7 ± 25.8	<0.001**	98.8 ± 30.9	0.002*
	Pull	1107.3 ± 32.5		211.0 ± 40.4	
Handling Direction	Up	1118.7 ± 29.8	<0.001**	156.8 ± 62.0	<0.001**
	Down	1011.3 ± 28.7		153.0 ± 71.1	
Interaction effect					
Slope* HT			<0.001**		<0.001**
Slope*HD			0.068		0.144
HT*HD			0.001*		<0.001**
Slope*HT*HD			<0.001**		<0.001**

HT, handling type; HD, handling direction.
Data were analyzed by the three-way repeated measured ANOVA test.
* *p-value* <0.05 and ** *p-value* <0.001.

Table 3
The effects of handling type, move cart in handling direction, and ramp slope on compression and shear forces L4-L5 in workers

Lumbar spinal load		Degree of ramp slope 0° Mean ± SD			10° Mean ± SD	15° Mean ± SD	20° Mean ± SD	*p-value*[*]
Compression force (N)								
	Push forward	638.0 ± 147.0	**Move up**	**PsUF**	1224.0 ± 274.8	1392.2 ± 318.8	1444.4 ± 354.4	<0.001**
				PlUB	911.0 ± 253.0	1118.1 ± 360.2	1582.8 ± 521.5	<0.001**
					<0.001**	<0.001**	0.044*	
	Pull backward	637.1 ± 139.7	**Move down**	**PsDB**	830.1 ± 228.2	971.2 ± 293.3	1041.7 ± 342.1	<0.001**
				PlDF	1077.6 ± 215.7	1205.5 ± 344.1	1688.5 ± 567.0	<0.001**
	p-value[†]	0.978			<0.001**	0.001**	<0.001**	
Shear force (N)	**Push forward**	127.9 ± 17.1	**Move up**	**PsUF**	108.5 ± 21.4	97.4 ± 29.0	87.6 ± 32.6	<0.001**
				PlUB	194.9 ± 18.8	218.7 ± 19.1	254.1 ± 29.0	<0.001**
				p-value[†]	<0.001**	<0.001**	<0.001**	
	Pull backward	165.2 ± 17.6	**Move down**	**PsDB**	95.4 ± 19.6	78.8 ± 20.8	67.0 ± 25.8	<0.001**
				PlDF	203.3 ± 16.9	222.1 ± 18.5	264.2 ± 31.1	<0.001**
	p-value[†]	<0.001**		***p-value***[†]	<0.001**	<0.001**	<0.001**	

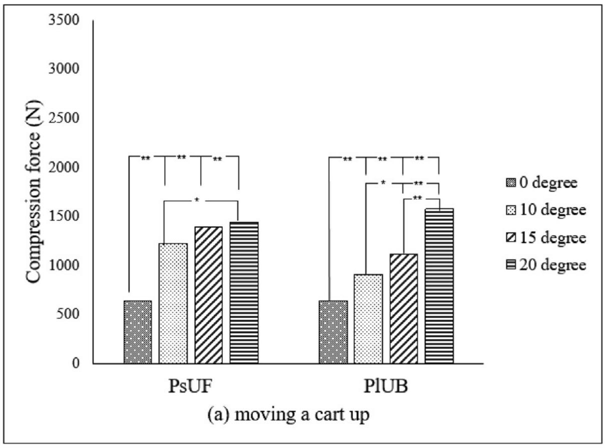
PsUF, push-up forward; PlUB, pull-up backward; PlDF, pull down forward; PsDB, push down backward.
* *p-value* <0.05 and ** *p-value* <0.001.

[*] *p*-value of within group comparison analyzed by the three-way repeated measured ANOVA test.

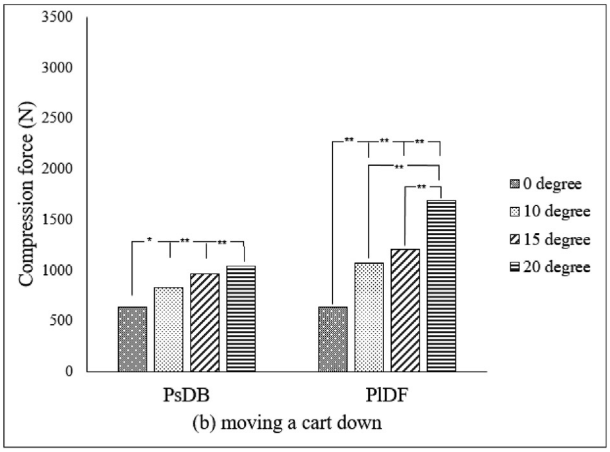
[†] *p*-value of multiple comparison analyzed by the Bonferoni's correction test.

increase in the angle of the slope caused the direction of the gravity force to be parallel to the axis of the spine. These also resulted in the increment of compression forces in the spine.

HTs also affected the compression force in the spine. The HTs consisted of two methods: pulling and pushing. In this study, a difference was found in compression force between the two HTs that were found both when moving up and down. Commonly, to move a cart up the ramp by walking forward and down by walking backwards required using the pushing method. On the contrary, walking up backward and walking down forward used the pulling

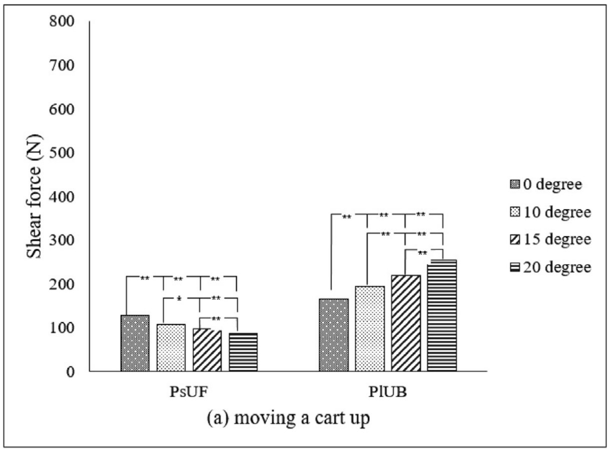


(a) moving a cart up

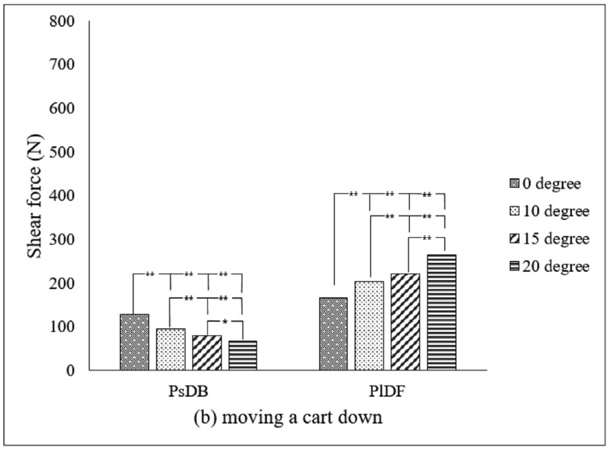


(b) moving a cart down

Fig. 3. Multiple comparison of L4/5 compression force among four degrees of slope and moving a cart up (a) and down (b) on ramp in different handling types including push-up forward (PsUF), pull-up backward (PlUB), pull down forward (PlDF), and push down backward (PsDB). * *p-value* <0.05 and ** *p-value* <0.001.



(a) moving a cart up



(b) moving a cart down

Fig. 4. Multiple comparison of L4/5 shear force among four degrees of slope and moving a cart up (a) and down (b) on ramp in different handling types including push-up forward (PsUF), pull-up backward (PlUB), pull down forward (PlDF), and push down backward (PsDB). * *p-value* <0.05 and ** *p-value* <0.001.

method. The different HTs required different postures and muscle activities [44], and affected the load on the spine. From the results, when the slope of the ramp increased, the pulling method caused a higher compression force than pushing at the same ramp angle particularly when moving down on the ramp. Nevertheless, while moving up at 10 and 15° of ramp with pushing, the compression force was higher than that of pulling. This may have resulted from the increment of trunk leaning while pushing when compared with pulling. When the ramp slope was up to 20°, the upper body was more upright in pushing. This explains why the compression force from pulling was greater than pushing at 20° of slope.

However, different associations between HT and slope were shown for the antero-posterior (AP) shear force. A decrease of shear forces was observed throughout the pushing method and increased while using the pulling method when the slope of the ramp increased. The change in AP spinal shear force depends on the posture while moving a cart on the ramp. Especially, the trunk leaning forward posture, having a greater moment arm, increases the shear force on the lumbar spine. For pushing, a change in the direction of the hand force was found, which was close to the HD, resulting in an increment of shoulder flexion and decrease in the trunk leaning forward position. Those posture changes were caused by the higher position of the cart and the handle located higher than the body of participants when the slope of the ramp increased. Therefore, this led to a reduced AP shear force. On the other hand, when pulling, the trunk tends to be in the leaning forward posture, the result of the cart being lower than the body. Therefore, the increase in trunk moments can lead to the increment of AP shear forces when the slope increases. A similar result of the effect of ramp gradient on spinal loading also was reported in a recent study. In 2013, Nimbarte et al. [18] evaluated the effects of load and floor gradient on L5/S1 compression force while pushing a cart on a ramp. Their results showed similar outcomes with this present study, i.e., the compression and shear forces increased at steep slopes of the ramp. However, the related study investigated only the low slopes of the ramp (0, 5, and 10°), and their results showed higher spinal loads than the present study. This difference may have been due to the different types of carts and the biomechanics model used to estimate the spinal loads.

4.1. Recommendation

In this study, spinal loads were used to determine the appropriate slope of the ramp and techniques for moving a cart. National Institute for Occupational Safety and Health [45] set the recommended safety limit for acceptable compression loads on the spine at 3400 N. The safety limit of the AP shear force less than 500 N was also recommended by McGill in 2015 [46]. From our results, the maximum compression and AP shear force were 1688 N and 264 N at 20 degrees of slope, respectively. These values are lower than the recommended safety limit. The results of this study demonstrated that most of the pushing techniques have low compression force and low AP shear. However, most of the pulling task had both high compression and AP shear force. Therefore, the pushing technique, exhibiting small values of compression and shear stress, is recommended for moving a cart on a high slope ramp. Moreover, when pushing a cart on a large gradient ramp (15 and 20°), the level of the cart will rise causing the handle height to be close to shoulder level. These place the trunk in an upright position and arms are in line with the direction of the force from the cart, which can generate more force for pushing. However, certain conditions such as moving down a ramp requires a pulling technique to move a cart because the workers need to see the way ahead while moving objects for safety. When pulling on the ramp, the cart and handle will be lower, causing the body to have more flexion, and affecting the shear force in the spine. Thus, when it becomes necessary to pull down the ramp, using an adjustable height handle of a cart, decreasing trunk flexion will reduce the shear forces.

4.2. Limitations

The present study included some limitations that should be considered before applying to a real situation. First, the handle height of this study was set as to the height of the waist; thus, pushing or pulling a cart with different levels of handle height may have demonstrated different results.

Second, the displacement of horizontal and coronal planes was not used to calculate the spinal loading in 3DSSPP software. In this present study, the four wheels of the cart were fixed and no movement in horizontal and coronal planes was assumed. Consequently, the results may differ from the actual situation involving a twisted torso or arms. Third, during PlUB and PlDF tasks, the front wheels of the cart were lifted off the floor causing movement with only two wheels which may have affected the posture of the participants while moving the cart. In addition, this study investigated only the spinal load to determine the risk of injury from work. Indeed, muscle activities are another factor affecting work injuries. Therefore, a future study should evaluate muscle activities of the limbs and torso together with the spinal load to support the selection of the most appropriate technique.

5. Conclusion

This study aimed to investigate effect of slope and HT on spinal loading. When ramp gradient increased, the increment of lumbar compression and AP shear force were found in both pushing and pulling techniques. However, AP shear force was reported both to increase and decrease depending on the HT used. Therefore, using appropriate HT could reduce the risk of muscle and joint injuries. The pushing method was best recommended for moving a cart on high ramp gradients.

Conflict of Interest

All authors do not have any potential conflicts of interest to declare.

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References

[1] Jansen JP, Hoozemans MJ, van der Beek AJ, Frings-Dresen MH. Evaluation of ergonomic adjustments of catering carts to reduce external pushing forces. Appl Ergon 2002;33(2):117–27.
[2] da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am J Ind Med 2010;53(3):285–323.
[3] Hoogendoorn WE, van Poppel MNM, Bongers PM, Koes BW, Bouter LM. Physical load during work and leisure time as risk factors for back pain. Scand J Work Environ Health 1999;25(5):387–403.
[4] Chaffin DB, Andersson G, Martin BJ. Occupational biomechanics. New York: Wiley; 1999.

[5] Baril-Gingras G, Lortie M. The handling of objects other than boxes: univariate analysis of handling techniques in a large transport company. Ergonomics 1995;38(5):905–25.

[6] Kumar S. Upper body push-pull strength of normal young adults in sagittal plane at three heights. Int J Ind Ergon 1995;15(6):427–36.

[7] Snook SH. The design of manual handling tasks. Ergonomics 1978;21(12):963–85.

[8] Garg A, Moore JS. Epidemiology of low-back pain in industry. Occup Med 1992;7(4):593–608.

[9] Hoozemans MJ, van der Beek AJ, Frings-Dresen MH, van Dijk FJ, van der Woude LH. Pushing and pulling in relation to musculoskeletal disorders: a review of risk factors. Ergonomics 1998;41(6):757–81.

[10] Winkel J. On the manual handling of wide-body carts used by cabin attendants in civil aircraft. Appl Ergon 1983;14(3):162–8.

[11] Engels JA, Van Der Gulden J, Senden TF, van't Hof B. Work related risk factors for musculoskeletal complaints in the nursing profession: results of a questionnaire survey. Occup Environ Med 1996;53(9):636–41.

[12] Snook SH, Ciriello VM. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics 1991;34(9):1197–213.

[13] Kuorinka I. Work related musculoskeletal disorders (WMSDs). A reference book for prevention; 1995. p. 46–53.

[14] Hashim N, Kamat SR, Halim I, Othman MS. A study on push-pull analysis associated with awkward posture among workers in aerospace industry. Age 2014;25(5).

[15] Meenaxi T, Sudha B. Causes of musculoskeletal disorder in textile industry. Int Res J Soc Sci 2012;1(4):48–50.

[16] Lind CM. Pushing and pulling: an assessment tool for occupational health and safety practitioners. Int J Occup Saf Ergon 2018;24(1):14–26.

[17] Cole DC, Van Eerd D, Bigelow P, Rivilis I. Integrative interventions for MSDs: nature, evidence, challenges & directions. J Occup Rehabil 2006;16(3):351–66.

[18] Nimbarte AD, Sun Y, Jaridi M, Hsiao H. Biomechanical loading of the shoulder complex and lumbosacral joints during dynamic cart pushing task. Appl Ergon 2013;44(5):841–9.

[19] Lett KK, McGill SM. Pushing and pulling: personal mechanics influence spine loads. Ergonomics 2006;49(9):895–908.

[20] Bennett A, Todd A, Desai S. Pushing and pulling, technique and load effects: an electromyographical study. Work 2011;38(3):291–9.

[21] Chaffin DB. Manual materials handling and the biomechanical basis for prevention of low-back pain in industry—an overview. Am Ind Hyg Assoc J 1987;48(12):989–96.

[22] Thelen DG, Ashton-Miller JA, Schultz AB. Lumbar muscle activities in rapid three-dimensional pulling tasks. Spine 1996;21(5):605–13.

[23] Argubi-Wollesen A, Wollesen B, Leitner M, Mattes K. Human body mechanics of pushing and pulling: analyzing the factors of task-related strain on the musculoskeletal system. Saf Health Work 2017;8(1):11–8.

[24] The Center for Ergonomics of University of Michigan. 3D static strength prediction program [Internet]. [cited 2017 Sep 2]. Available from: https://c4e.engin.umich.edu/tools-services/3dsspp-software/.

[25] Çakıt E. Ergonomic assessment of airport shuttle driver tasks using an ergonomic analysis toolset. Int J Occup Saf Ergon 2018;24(2):286–93.

[26] Wiggermann N. Biomechanical evaluation of a bed feature to assist in turning and laterally repositioning patients. Hum Factor. 2016;58(5):748–57.

[27] Tafazzol A, Aref S, Mardani M, Haddad O, Parnianpour M. Epidemiological and biomechanical evaluation of airline baggage handling. Int J Occup Saf Ergon 2016;22(2):218–27.

[28] Gutiérrez M, Monzó J. Prevalence of low back disorders among female workers and biomechanical limits on the handling of load and patients. Work 2012;41(Suppl. 1):2364–9.

[29] Cooper G, Ghassemieh E. Risk assessment of patient handling with ambulance stretcher systems (ramp/(winch), easi-loader, tail-lift) using biomechanical failure criteria. Med Eng Phys 2007;29(7):775–87.

[30] Botti L, Galizia FG, Mora C, Zecchi G. A thorough investigation on pushing activities in industry: the impact of the variation in the speed of motion and load conditions on initial and sustained forces. Appl Ergon 2020;85:103080.

[31] The effect of speed variation on initial and sustained forces during pushing and pulling activities: a preliminary study. In: Botti L, Mora C, Zecchi G, Baruffaldi G, editors. international conference on applied human factors and ergonomics. Springer; 2018.

[32] Giagloglou E, Radenkovic M, Brankovic S, Antoniou P, Zivanovic-Macuzic I. Pushing, pulling and manoeuvring an industrial cart: a psychophysiological study. Int J Occup Saf Ergon 2019;25(2):296–304.

[33] El Ouaaid Z, Shirazi-Adl A, Plamondon A. Trunk response and stability in standing under sagittal-symmetric pull–push forces at different orientations, elevations and magnitudes. J Biomech 2018;70:166–74.

[34] Lee J, Nussbaum MA, Kyung G. Effects of work experience on work methods during dynamic pushing and pulling. Int J Ind Ergon 2014;44(5):647–53.

[35] Weston EB, Aurand A, Dufour JS, Knapik GG, Marras WS. Biomechanically determined hand force limits protecting the low back during occupational pushing and pulling tasks. Ergonomics 2018;61(6):853–65.

[36] Lee KS, Chaffin DB, Herrin G, Waikar A. Effect of handle height on lower-back loading in cart pushing and pulling. Appl Ergon 1991;22(2):117–23.

[37] Ohnishi A, Takanokura M, Sugama A. Evaluation of interhandle distance during pushing and pulling of a four-caster cart for upper limb exertion. Saf Health Work 2016;7(3):237–43.

[38] Kim CS, Lee D, Kwon S, Chung MK. Effects of ramp slope, ramp height and users' pushing force on performance, muscular activity and subjective ratings during wheelchair driving on a ramp. Int J Ind Ergon 2014;44(5):636–46.

[39] Kao HC, Lin CJ, Lee YH, Chen SH. The effects of direction of exertion, path, and load placement in nursing cart pushing and pulling tasks: an electromyographical study. PloS One 2015;10(10).

[40] Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, Jørgensen K. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 1987;18(3):233–7.

[41] Oxford Metrics plc company. Plug-in gait full body model [Internrt]. [cited 2017 Sep 10]. Available from: https://docs.vicon.com/display/Nexus25/Take+subject+measurements+for+Plug-in+Gait#TakesubjectmeasurementsforPlug-inGait-SubjectmeasurementsforPlug-inGaitfullbodymodel.

[42] Blazquez IN, Warren BL, O'Hanlon AM, Silvestri LR. An adequate interset rest period for strength recovery during a common isokinetic test. J Strength Cond Res 2013;27(7):1981–7.

[43] Parcell AC, Sawyer RD, Tricoli VA, Chinevere TD. Minimum rest period for strength recovery during a common isokinetic testing protocol. Med Sci Sports Exerc 2002;34(6):1018–22.

[44] Knapik GG, Marras WS. Spine loading at different lumbar levels during pushing and pulling. Ergonomics 2009;52(1):60–70.

[45] National Institute for Occupational Safety. Work practices guide for manual lifting: US dept. Of health and human services. Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science; 1981.

[46] McGill SM. Low back disorders: evidence-based prevention and rehabilitation. Human Kinetics; 2015.