Applied Ergonomics 1991, 22.2, 117–123

Effect of handle height on lower-back loading in cart pushing and pulling

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This paper presents results of a study conducted to estimate lower back loadings in cart pushing and pulling. Experiments were conducted in the laboratory using a cart. Six subjects with different weights (ranging from 50 to 80 kg) were tested for three different pushing and pulling forces (98, 196 and 294 newtons), three different heights of exertion (660, 1090 and 1520 mm high) and two different moving speeds (1·8 and 3·6 km/h). It was found that, in general, pushing a cart results in lesser lower-back loading than pulling. Subject body weight affected the lower-back loadings more significantly in pulling (50% increase as body weight increased from 50 kg to 80 kg) than in pushing (25% increase). Handle height of 1090 mm was found to be better than other handle heights in pushing while 1520 mm handle height was better for pulling in reducing lower-back loadings.

Keywords: Human performance, handles, back, physical exertion

Introduction

Every year, many over-exertion injuries occur due to pushing and pulling activities in industry. In the state of California, during 1987, there were 13 572 industrial injuries due to pushing and pulling tasks (Department of Industrial Relations, 1988). This number accounts for 11·8% of total over-exertion injuries in the state. A similar statistic exists in many other states, which shows the significance of pushing and pulling tasks to injuries. In Michigan, pushing and pulling accounts for 20·3% of total over-exertion injuries. These are 7·5% of the total injuries in workplaces (MIOSH, 1988). In the state of Ohio, in 1985 alone, 47·6% of injuries which involved carts and hand-trucks were over-exertion injuries (Industrial Commission of Ohio, 1986).

Cart or hand-truck pushing and pulling are common dynamic tasks in the industrial environment. In these tasks, a worker must exert enough force to push or pull the cart and also should be ready to regain balance in case the cart moves unexpectedly. The moving object (a cart or a hand-truck) may not totally support the worker's body, as is possible in cases of isometric (static) pushing and pulling. This potential instability often causes the worker to take smaller steps (Fig. 1) or adopt awkward postures, resulting in the high over-exertion injury rate.

Figs. 1 and 2 illustrate simulated pushing by the same person. It shows how a person often assumes different postures in dynamic pushing compared with the posture assumed in isometric pushing for the same level of exertion. Differences also occur in pulling. This will affect lower back loading, which is posture dependent, and implies that the results of static pushing or pulling study may not be applicable to, or appropriate for dynamic pushing or pulling. A literature review showed that there is a lack of information concerning the effects of dynamic task variables such as the handle height, body weight, the required hand force level and the required moving speed of the cart on lower-back loading. Most previous pushing and pulling studies have examined only isometric or static pushing and pulling activities.

Two studies (Lee, 1982; Chaffin *et al*, 1983) have determined the required friction level between floor and the worker in order to reduce slip and fall accidents involving cart pushing and pulling. These studies investigated the handle location that minimises the required friction level between the floor and the worker. However, the handle location should not be determined by friction level alone. The potential effect of posture and the resulting lower-back loading must be taken into account in determining handle location. The objective of this study was to investigate the effects of different handle heights on lower-back loadings in dynamic pushing and pulling tasks.

Background

In the past, primary interest in pushing and pulling studies (Ayoub and McDaniel, 1974; Chaffin *et al*, 1983; Gaughran and Dempster, 1956; Kroemer, 1974; Snook *et al*, 1969) has been the development of volitional isometric strength data for specific tasks. In several of these studies, a volunteer group was required to demonstrate maximum exertion strength on some type of load cell while in a seated position (Gaughran and Dempster, 1956; Hugh-Jones, 1947). Kroemer (1969) studied 65 different pushing positions and measured the resulting maximal isometric forces when the

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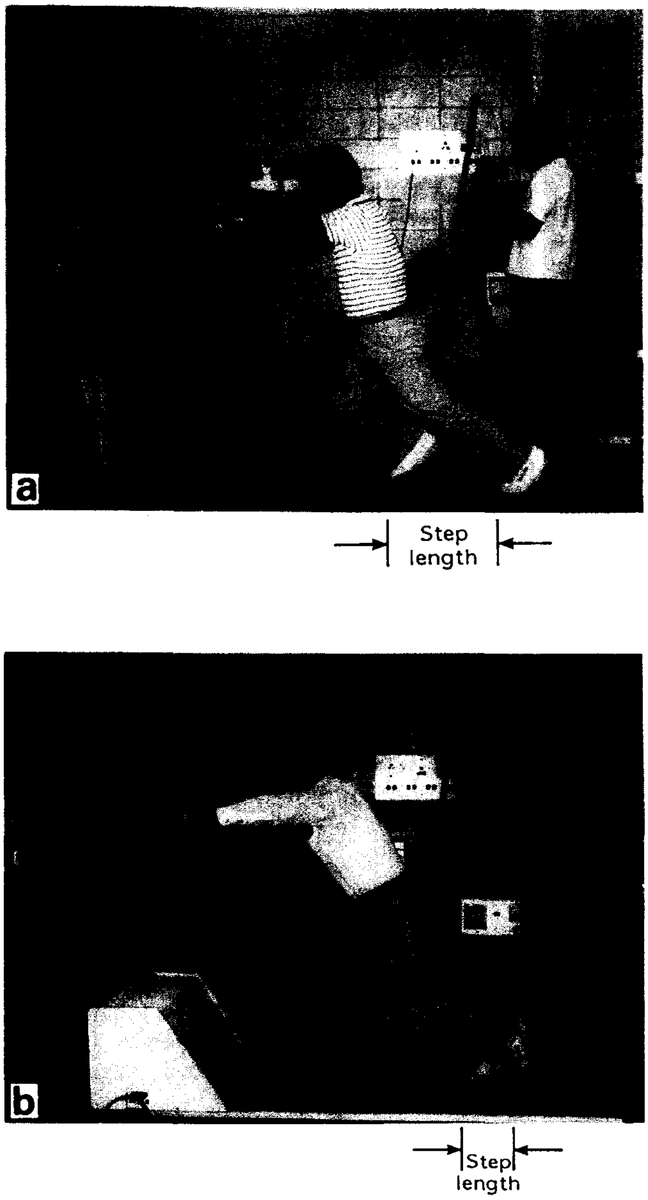


Fig. 1 Body posture in (a) isometric pushing (940 N) and (b) dynamic pushing (800 N) exerting maximum force

subjects were assisted by bracing their feet or hips against an external structure. Kroemer and Robinson (1971) also studied static pushing forces with varied shoe-floor friction levels. Grieve (1983), in his study of isometric exertion, showed that strength/weight ratios, direction of exertion and height of the workpiece influence frictional requirements during manual strength measurement on a non-slip floor.

Ayoub and McDaniel (1974) measured the strength of subjects in isometric pushing and pulling against a wall as a function of different body configurations. They also estimated the load on the lumbar spine during these volitional exertions. However, neither Kroemer (1969) nor Ayoub and McDaniel (1974) considered a dynamic situation where the worker moves or walks. Snook *et al* (1969) found large differences in volitional hand forces exerted at different heights when pulling while walking on a high-traction treadmill, but not when pushing.

Snook (1978) found in his dynamic pushing and pulling test that 50% of a working population would accept a maximum of 588 N of initial force (isometric exertion) if they were asked to push for a distance of 2·1 m at a handle height of 950 mm, once every 8 h. But the population would be willing to exert a maximum of only 402 N of sustained force (similar to dynamic forces in our study) if the subjects were asked to pull under similar conditions. However, because the treadmill in his study was powered by the forces exerted by the subject pushing or pulling against a stationary bar, the effect of speed was not investigated.

These studies do not offer information on the level of lower-back stress resulting from dynamic pushing and pulling tasks. Limitations of the above mentioned research suggest the need for a study which would yield more

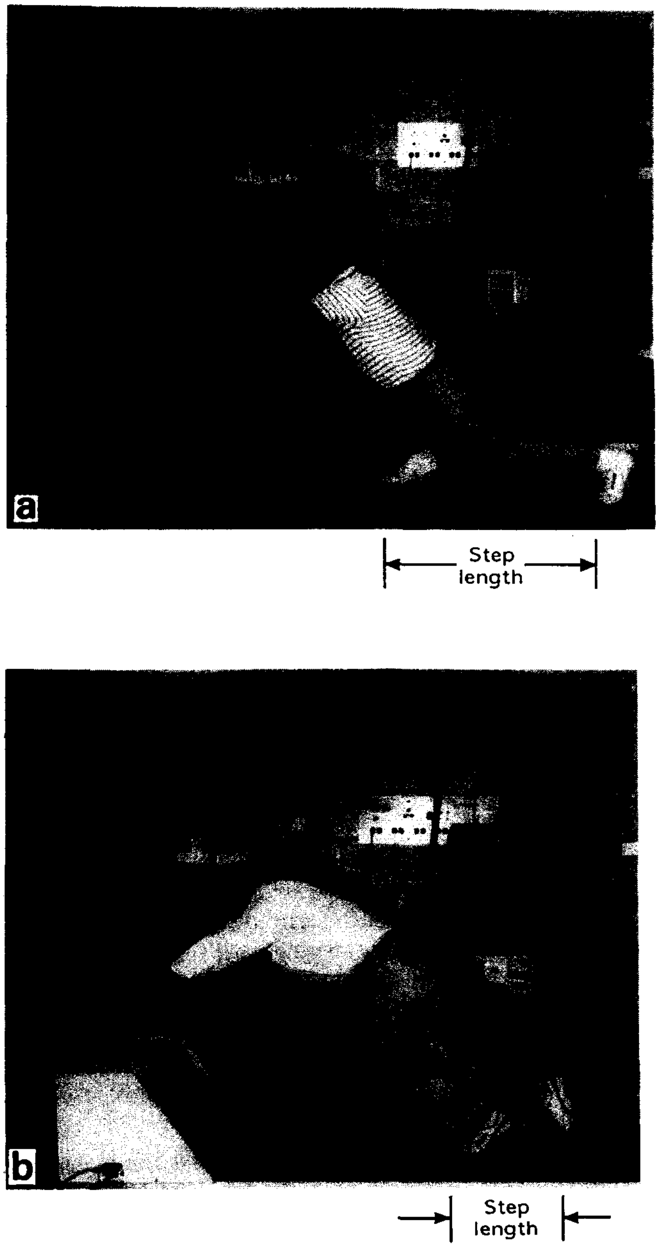


Fig. 2 Body posture in (a) isometric pushing and (b) dynamic pushing exerting 178 N force

thorough information through an experimental approach incorporating the effects of task and personal factors on slip potential and lower-back stress in dynamic pushing and pulling tasks.

Method

An experiment was conducted to investigate the effects of personal and task factors on the resulting lower-back stress in dynamic pushing and pulling in the laboratory. A dynamic biomechanical model (Bloswick *et al,* 1984; Lee, 1982; Redfern and Andres, 1984) that assumes the human body to be a system of 11 links, was used to estimate the lower-back stress using the hand forces, speed of body movement and body configuration determined from the data collected in the experiment.

Subjects

Four male and two female students ranging in age from 20 to 30 years (average 23·4 years) participated in the experiment. Their weight ranged from 50 kg to 80 kg and the stature ranged from 1620 mm to 1753 mm. Table 1 shows the anthropometric data for all the subjects. No subject had a history of back pain or previous back trauma. Before the experiment, all the subjects were informed of the risks, and were given verbal and written instructions about the procedure of the experiment. The link lengths of the subjects, required as input to the biomechanical model, were measured before the experiment using the linear-dimension method (Roebuck *et al,* 1975). The subjects were also photographed in a standing position. During the experimental trials, subjects were required to wear shoes with a rubber sole to obtain a maximum coefficient of friction (> 0·6) between the shoe sole and floor (estimated by Kromer and Robinson's (1971) method).

Equipment

The equipment used included a cart simulator, a force platform, a 35 mm camera with a strobe flash and a single flash, a frequency generator, a tri-axial load cell at the handle of the cart simulator, an oscilloscope, a strip chart recorder and a digital computer.

The cart simulator (Fig. 3) used in the study was a special structure 1800 mm high and 770 mm wide, that was designed to roll on a level track to minimise friction. The bar handle was vertically adjustable between the top and bottom of the simulator. A tri-axial load cell was attached to this handle so that the X, Y and Z components of the pushing or pulling force on the handle could be measured.

Table 1: Subject anthropometry

Subject	Sex	Stature (mm)	Weight (kg)
S1	Male	1690	60·3
S2	Female	1620	50·0
S3	Male	1710	75·0
S4	Male	1705	80·0
S5	Female	1695	59·1
S6	Male	1753	62·3

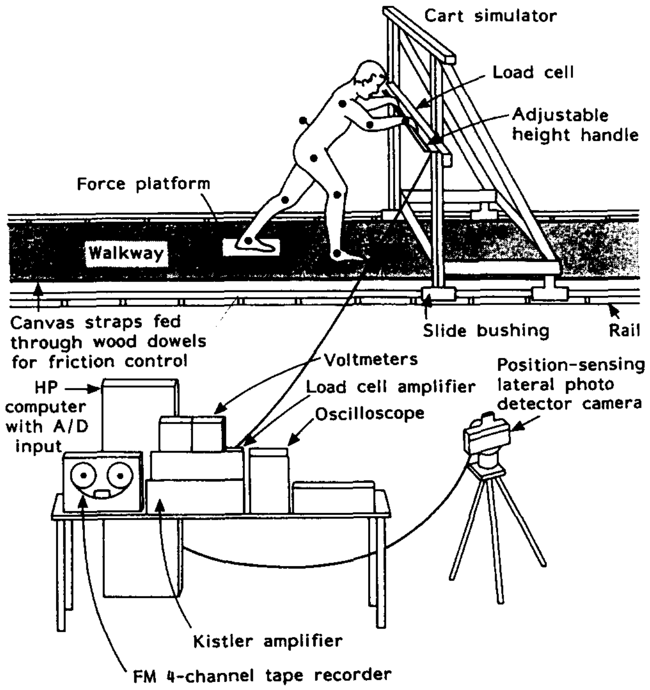


Fig. 3 Experimental set-up

Lower-back stress estimation using the biomechanical model

A biomechanical model (Lee, 1982) was used in this study to estimate the lower-back stress since this stress cannot be measured easily. The model was a sagittal plane model. It assumed that all external hand forces acting on the body are at the centre of the grip of the hands, and all external foot forces acting on the body do so at one contact point (centre of the contact area of the heel or sole of each foot). In mechanics, several forces can be effectively brought to one point.

The model assumed the human body to be made up of 11 solid links (hand, lower arm, upper arm, upper trunk and neck, lower trunk, right and left upper leg, right and left lower leg, right and left foot). The mass and principal moment of each link was determined according to Dempster *et al*'s (1964) data. The radius of gyration was determined as a percentage of segment of link length, according to Plagenhoef's data (Plagenhoef, 1966). The model estimated reactive forces and moments at joints and compressive forces at the L_5/S_1 disc.

Inputs needed for the biomechanical model were hand forces required to move the cart, body weight and body kinematics as functions of various cart motions. Since the model was a dynamic model, the Fourier series representation technique (Lee, 1982) was used for the calculation of angular velocities and accelerations of various links.

Experimental design

The independent variables in the experiment were cart counterforce (which is the same as the horizontal hand force but opposite in direction; it will be called hand force hereafter), subject's body weight, height of the handle and cart moving speed. The handle height was measured from the bottom of the subject's foot. These variables and their

Table 2: Values of variables used in the experiment

Hand force[1] (N)	Handle height[2] (mm)	Cart speed (km/h)
98	660	1·8
196	1090	2·7
294	1520	

[1] Horizontal force

[2] From the bottom of the foot

[3] Because of the dynamic nature of cart pushing and pulling, the hand forces varied slightly during the test. The hand forces listed in Table 2 represent the average hand force required to move the cart.

respective levels are listed in Table 2. In estimating the peak compressive forces at the intervertebral lumbosacral joint (L_5/S_1), measured hand forces at each time interval were used as an input to the biomechanical model. Each subject was tested for three different handle heights, three different levels of required hand forces in both pushing and pulling. The two required cart moving speeds (1·8 km/h and 3·6 km/h) for both pushing and pulling could be tested only for one handle height (1090 mm). The other handle heights were tested at lower speed only (1·8 km/h), to minimise potential for injuries. Pushing or pulling at these handle heights was found to be dangerous due to slipping and no data were collected for these handle heights at the higher cart speed. There were two replications for each of the feasible combinations of the experimental variables.

A hand force of 294 N was set as the limit in pushing as well as in pulling because when the hand force was increased beyond 294 N, the subjects could not perform the experimental task at a constant speed of 1·8 km/h.

Procedure

The subject began the task (pushing or pulling) at the starting point of the 6 m track and pushed or pulled the cart simulator the entire length of the track. A HP1000 computer was used to record hand force data at 10 ms intervals. The displacements of the body links were photographed using a camera with a strobe flash, at 67 ms intervals. Eleven reflective markers were attached to the subject at wrist, elbow, shoulder, L_5/S_1 disc, hip, left knee, right knee, left ankle, right ankle, right foot sole and left foot sole. The subjects were required to wear black leotards for good contrast. One reflective marker was attached to the side of the bar handle. These pictures were digitised using a digitiser (Graf/Pen) to obtain data for positions of each joint at each interval.

Table 3: Analysis of variance

(a) Pulling

Source	DF	Sum of Sq	Mean Sq	F value	Pr > F
Hand Force (F)	2	98873172	49436586	194·68	0·0001
Body Weight (W)	5	50424151	10084830	39·71	0·0001
Handle Height (H)	2	85643246	42821623	168·63	0·0001
F*W	10	15646764	1564676	6·16	0·0001
F*H	4	5117067	1279266	5·04	0·0016
H*W	10	6724482	672448	2·65	0·0105
F*W*H	20	10166650	508332	2·00	0·0225
Model	53	272595536	5143312	20·25	
Error	54	13712862	253941		
Total	107	286308398			

(b) Pushing

Source	DF	Sum of Sq	Mean Sq	F value	Pr > F
Hand Force (F)	2	25967091	12983545	65·06	0·0001
Body Weight (W)	5	6882187	1376437	6·90	0·0001
Handle Height (H)	2	8227826	4113913	20·61	0·0001
F*W	10	1348933	134893	0·68	0·7415
H*W	10	4170628	417062	2·09	0·0417
F*H	4	6001489	1500372	7·52	0·0001
F*W*H	20	5200496	260024	1·30	0·2185
Model	53	57798653	1090540	5·46	
Error	53	10577154	199568		
Total	106	68375807			

Results

The data were analysed to find the effect of individual factors on compressive forces at the L_5/S_1 disc. Since the peak compressive forces are of our interest, the peak compressive forces during each pushing and pulling cycle for different experimental conditions were identified and used for the analysis. Therefore, all compressive forces mentioned hereafter represent the peak compressive forces. Analysis of variance (ANOVA) with the fixed model was performed on the compressive forces with three independent variables (hand force, handle height, body weight). A linear regression analysis was performed to test the significance of slopes. The significance level used was $p = 0{\cdot}01$. Table 3 shows the summary of ANOVA. The effect of each factor is discussed separately below:

The effect of body weight

ANOVA shows that the body weight significantly affects the compressive force ($p < 0{\cdot}01$) in both pushing and pulling. Body weight also shows a significant interaction effect with hand force level in pulling. Because of this interaction effect, the compressive forces for different body weight were presented for different hand force in Fig. 4. It was found that generally in pulling, the compressive force increased as the body weight increased. Although, there was also a trend of increasing compressive force in pulling, a linear regression analysis showed that the slope was not statistically significant ($p < 0{\cdot}01$). As expected, high handle pulling resulted in the smallest compressive forces compared with forces with other handle heights. This could be because the effect of upper body weight on L_5/S_1 was reduced by the hand force at high handle heights.

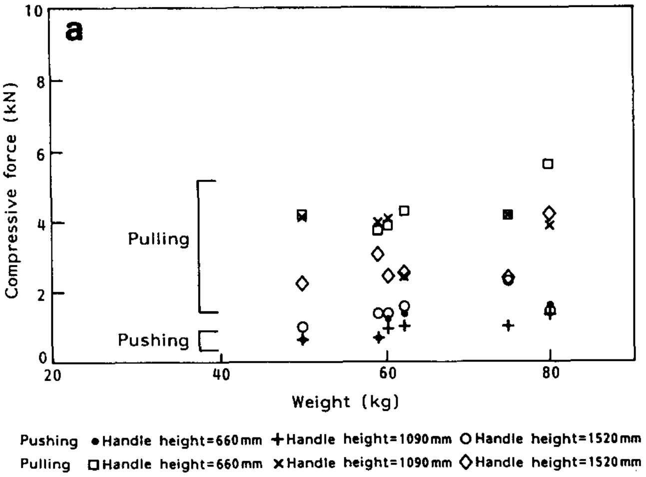
A subject with 50 kg of body weight could not complete her low handle height (6600 mm) pushing task at 294 N hand force level because of slipping. However, the compressive force was not a limiting factor since these tasks resulted in a relatively small compressive force value for this subject. The predicted compressive force was less than NIOSH's action limit value of 3430 N (NIOSH, 1981). In general, it was found that pulling tasks caused about twice as much compressive forces as pushing tasks when using a simple single muscle equivalent biomechanical model (Lee, 1982). The slope of the regression line – that is, rate of increase in compressive force with increase in body weight – was greater in pulling than in pushing.

The effect of hand forces

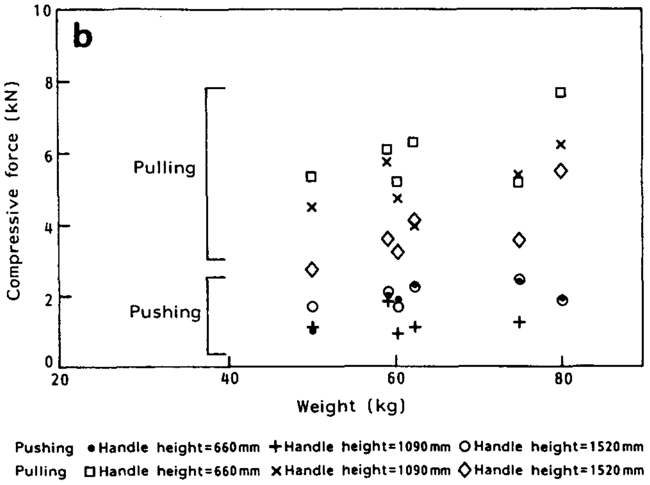
ANOVA shows that the hand force significantly affects the compressive force at L_5/S_1 ($p < 0{\cdot}01$) in both pushing and pulling. It also shows a significant interaction with handle height ($p < 0{\cdot}01$). Fig. 5 shows the compressive force for each hand force averaged over body weight. A linear regression analysis shows that in both pushing and pulling, the compressive force on the L_5/S_1 disc increased as the horizontal hand force on the handle increased. The slopes were statistically significant ($p < 0{\cdot}01$). It was found that in pulling, as the height increased, the compressive forces decreased. However, in pushing, the compressive forces were not affected by the handle height.

The effect of handle height

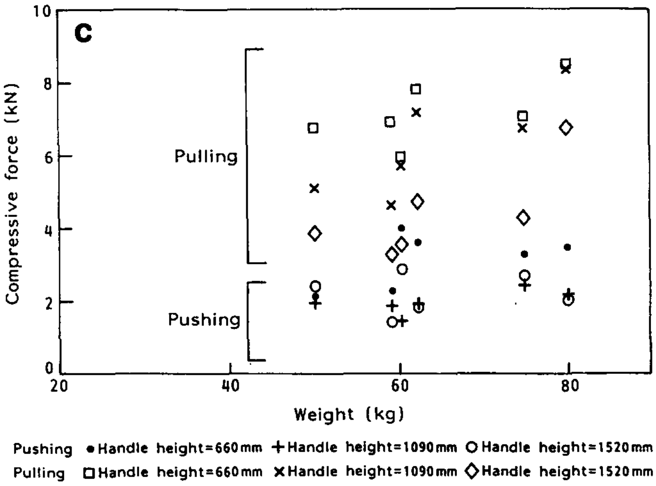
ANOVA shows that handle height significantly affects the compressive force at L_5/S_1 disc ($p < 0{\cdot}01$). Pairwise



Hand force = 98 N



Hand force = 196 N



Hand force = 294 N

Fig. 4 Maximum compressive force for different body weights at cart moving speed of 1·8 km/h in pushing and pulling for hand forces of (a) 98 N, (b) 196 N and (c) 294 N

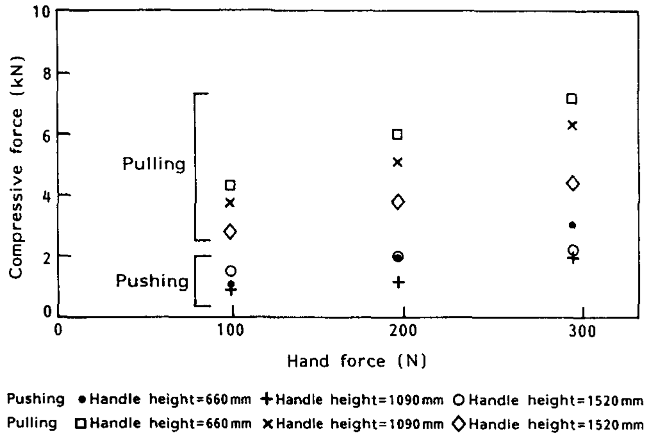


Fig. 5 Maximum compressive force for different hand forces at cart moving speed of 1·8 km/h in pushing and pulling aggregated for all subjects

t-tests ($p < 0{\cdot}01$) show that pulling resulted in a significantly greater compressive force on the L_5/S_1 disc than pushing for all subjects regardless of the handle height and the hand force. Fig. 6 shows the compressive force for each handle height averaged over all other test conditions. The smaller compressive force for the 1090 mm handle height in pushing may be due to a smaller vertical hand force which in turn reduces the torque (Torque = moment x hand force).

The effect of cart speed

Experimental trials involving a cart speed faster than 3·6 km/h could not be performed because the task resulted in greater horizontal foot forces (Y) and thus caused slipping. This happened mostly in the low-handle (660 mm from the floor) pushing and high-handle (1540 mm from the floor) pulling. For reasons explained in the method section, the speed effect was tested only for 1090 mm high handle because of high injury potential at other handle heights. In low-handle pushing, the vertical foot force decreased to a great extent since the vertical hand force increased with increase in speed. This increase in force supported some of the body weight.

Fig. 7 shows the effect of cart speed on the compressive force at the L_5/S_1 disc. Pairwise t-test shows that as the speed increased, the maximum compressive forces at the L_5/S_1 disc increased ($p < 0{\cdot}01$) as expected. The rate of increase in the compressive force was much higher in pulling than in pushing.

The effect of an increase in cart speed was different for different handle heights. Middle handle height in pushing and high handle height in pulling showed the least increase in the compressive force with increasing cart speed.

Analyses

A stepwise regression procedure was employed for further analysis to obtain insight into the relationships between the independent variables and the dependent variable of peak compressive force at the L_5/S_1 disc. The variables considered for the regression model were subject's body weight, subject's stature, hand force, handle height and various interactions of these variables. Interaction variables were chosen based upon the results of the ANOVA. The stature/handle-height relationship seemed biomechanically more important to the compressive forces than the subject's stature alone. This ratio represents the relative height of the handle compared with the stature. Therefore a new variable, height factor, which represents this ratio was defined and used instead of stature and handle height as follows:

H = (stature − handle height)/stature

where

H = height factor

Separate analyses were performed on the data collected for pushing tasks and for pulling tasks. SAS (1989) program was used for this analysis.

The regression analysis performed on the data for pushing tasks yielded the following relationship between the peak

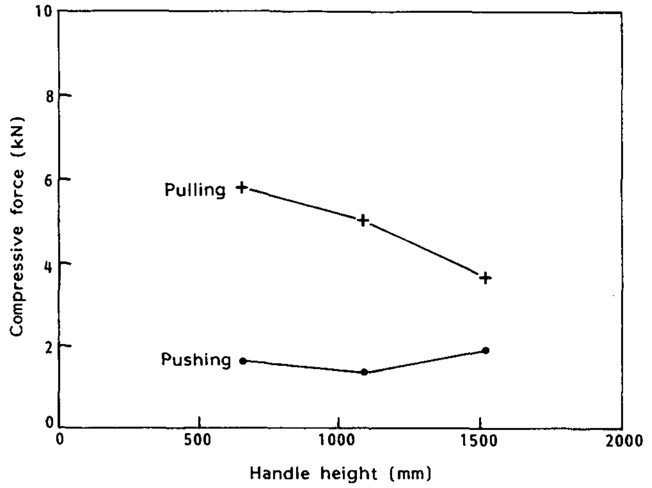


Fig. 6 Maximum compressive force for different handle heights in pushing and pulling aggregated for all subjects

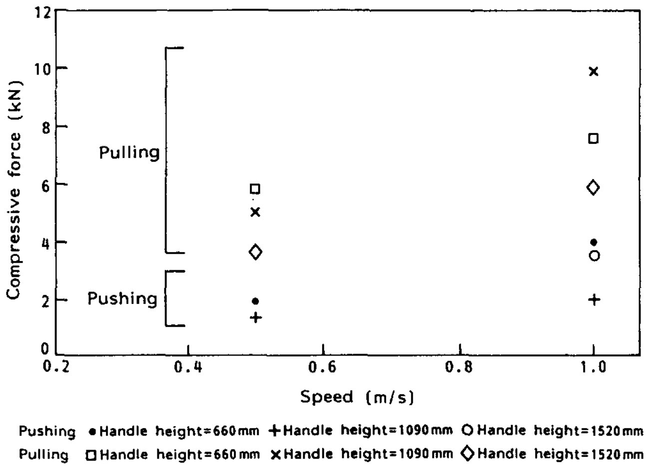


Fig. 7 Maximum compressive force for cart moving speeds for all conditions in pushing and pulling aggregated for all subjects

compressive force at the L_5/S_1 disc and the independent variables:

$$Y_{\text{pushing}} = 298 + 16{\cdot}62W - 2261{\cdot}86H + 0{\cdot}0254WF + 12{\cdot}67FH$$

where

Y_{pushing} = peak compressive force at L_5/S_1 disc in pushing

W = subject weight (kg)

H = height factor

F = horizontal hand force (N)

The value of the multiple correlation r^2 was 0·52. The peak compressive force seemed to be affected by the anthropometric variables of subject weight and subject height. These variables affect the moment arm and the mass of different body links, thus affecting the compressive force which is in agreement with the theory of the biomechanical model. It was also affected, though to a limited extent, by the interaction of the body weight, stature and the force exerted by the subject.

The regression analysis performed on the data for pulling tasks yielded the following relationship between the peak compressive force at L_5/S_1 disc and the independent variables:

$$Y_{\text{pulling}} = 1923 - 9{\cdot}52F + 1696{\cdot}99H + 0{\cdot}26WF + 12{\cdot}70FH$$

where

Y_{pulling} = peak compressive force at L_5/S_1 disc in pulling

W = subject weight (kg)

H = height factor

F = horizontal hand force (N)

The value of the multiple corrleation r^2 for this relationship was 0·78. The model showed that the interaction between the subject weight and handle force increased the peak compressive force on the L_5/S_1 disc. This force was also increased by the interaction of relative handle height location (represented by H) and the hand force required.

Summary

In cart pushing and pulling, light body weight and slow cart speed are good for lowering the compressive force at the L_5/S_1 disc. The required hand force also affects the compressive force. In general, pushing results in lower compressive force than pulling for the same task conditions. However, the results need to be used with caution in designing pushing or pulling tasks because the handle height that reduces compressive force on the lower back may increase the slip potential. Therefore, the task may require a different handle height from the safety point of view.

Acknowledgement

The authors would like to express their gratitude to Mr James A. Foulke of the Center for Ergonomics in The University of Michigan for his help. This research was partially supported by research grants from NIOSH (No 210-81-3104) and NASA (No NAS 915244).

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