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Musculoskeletal Loading During Dynamic Two-Wheeled Cart Pushing and Pulling

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Abstract

Pushing and pulling of carts is a common manual material handling activity at various workplaces. Epidemiological studies have shown an association between the work-related pushing/pulling exertions and the symptoms of low back pain and shoulder complaints. It is currently unclear as to how the dynamic pushing/pulling tasks affect the musculoskeletal loading of the shoulder and low back. Therefore, the objective in the current study was to evaluate dynamic pushing/pulling tasks to quantify their effects on the musculoskeletal loading of major body joints. Six male participants performed two-handed forward pushing and one-handed forward pulling tasks using a two-wheeled hand cart to transfer loads of 25 kg and 35 kg. An eight-camera optoelectronic motion system configured with two ground reaction force platforms was used for data collection. The experimental data were exported in the C3D format, which were then used for running a full body musculoskeletal model to compute the biomechanical loading. The results showed that the weight transferred as well as the pushing/pulling technique had no effect on the loading of the L5S1 joint but significantly affected the loading of the shoulder joints, further indicating a possibility of higher risk of shoulder MSDs than low back MSDs during such exertions.

Keywords
Dynamic pushing and pulling, musculoskeletal loading, biomechanical modeling

1. Introduction

Manual materials handling (MMH) tasks commonly performed at workplaces primarily comprise of activities such as lifting/lowering, pushing/pulling, and carrying of loads [1]. Scientific research concerned with health complaints related to MMH has mainly been focused at lifting and carrying loads [2]. As lifting, carrying and holding are frequently cited in relation to low back pain [3-5], it is intuitive to recommend avoiding this type of activity. This has initiated changes in job design through implementation of a number of assistive devices or interfaces. As a result manual transport aids and vehicles, such as trolleys, carts, trucks, wheelbarrows, etc. are frequently used at work places to carry out MMH activities [6-7]. Although this has reduced the occurrence of lifting, carrying and holding, repetitive pushing and pulling activities have become increasingly common. It has been estimated that nearly half of MMH common at workplaces demands pushing and pulling exertions [8]. The occupations that demand pushing and pulling type of exertions on daily basis include healthcare [9-11], manufacturing [12], fire fighting [13], flight and rail catering [14-15], postal distribution [16], refuse collection [17], construction [18], garden raking [19], and retail, storage and warehousing [20].

Pushing and pulling type of exertions are implicated as a risk factor for the proliferation of musculoskeletal disorders (MSDs) of the low back and upper extremities in a number of studies [21-23]. A dose-response relationship between the work-related pushing/pulling exertions and complaints of shoulder pain was reported by Hoozemans et al. [23]. In another study by Smedley et al. [22], patient handling tasks that demand reaching, pushing, and pulling were identified as the physical risk factors for low back and shoulder MSDs. Van der Beek et al. [21] investigated the prevalence of musculoskeletal complaints in lorry drivers and found a significantly higher number of low back and upper extremities complaints in the lorry drivers who regularly pushed or pulled wheeled cages during the working day compared to those who only performed the driving task.

To gain insight into the causal relationship between the low back and shoulder MSDs and the pushing/pulling exertions, work-related pushing and pulling exertions were evaluated in a number of studies. Most of these existing studies primarily focused on investigating changes in the magnitude of hand forces corresponding to different pushing/pulling techniques [3, 6, 24] and the effect of pushing/pulling exertions on various physiological parameters [16, 25-27]. Studies that evaluated the effect of pushing/pulling exertion on the musculoskeletal loading are sparse and are primarily performed using static exertions [28]. Within industry, the commonly performed pushing and pulling exertions are dynamic in nature and several biomechanical models and epidemiologic studies suggested that the dynamic work was associated with a higher risk of injury compared to the static work [28-29]. Currently it is not clearly understood as to how the dynamic pushing/pulling exertions affect the musculoskeletal loading of major body joints. Therefore, the purpose of the present study was to quantify three-dimensional (3-D) musculoskeletal loading of the low back and shoulder joints during dynamic cart pushing and pulling tasks.

2. Methods

2.1 Approach

Human participants performed cart pushing/pulling tasks using two techniques (1) two-handed pushing while forward walking; (2) one-handed pulling while forward walking. Two weight conditions, 25 kg and 35 kg, were tested in this study. Whole body 3-D joint kinematics data were recorded using marker based optical motion analysis system. Kinematic data were then used to run a full body biomechanical model to quantify the musculoskeletal loading.

2.2 Participants

Six male participants participated in this preliminary study. The Physical Activity Readiness Questionnaire (PAR-Q) [30] was used to screen the participants for cardiac and other health problems (e.g. dizziness, chest pain, heart trouble). Age, weight, and height of the participants were 27.50(3.27) years, 66.2 (4.61) kg, and 172 (3.74) cm, respectively.

2.3 Experimental Design

A 2 × 2 full factorial experimental design was used. The independent variables were the technique ((1) two-handed pushing while forward walking; (2) one-handed pulling while forward walking) and load transferred (25 kg and 35 kg). The dependent variables were the 3-D musculoskeletal loading of the low back and shoulder joints. For the low back, compressive, anterior-posterior and medio-lateral shear forces were computed at the L5S1 joint. For the shoulder medio-lateral, infero-superior, and anterior-posterior forces were computed at the sternoclavicular, acromioclavicular, and glenohumeral joints.

2.4 Equipment

An eight-camera (MX-13 series) optical motion analysis system (Vicon, Nexus, UK) was used for recording the 3-D kinematic data. Two Kistler force plates (type 9286, Kistler Instrument Corp., Amherst, NY, USA) embedded in the wooden floor were used for recording the ground reaction force (GRF). AnyBody modeling system (AnyBody Technology, Denmark) was used for computing musculoskeletal loading. This is a full body biomechanical modeling system. Biomechanical models can be formulated using AnyScript modeling language. Models consist of bones, joints, and muscle-tendon units with real physiological properties. Joints are driven by experimentally obtained kinematic data. Muscle and joint reaction forces are computed by using inverse dynamic analysis.

2.5 Data Collection and Processing

The data collection session for each participant consisted of the following steps:

i) Upon arrival to the laboratory, each participant was introduced to the experimental set up (walkway, cart, data collection equipment, and loads to be handled with cart) and a brief explanation was provided to the participant about the research objectives. A set of demographic and anthropometric measurements were recorded. The participant then changed into the test shirt and pant and a set of thirty-nine reflective markers (diameter = 0.025 m) were affixed on the anatomical locations based on the Vicon Plug-in-Gait marker placement protocol. Additionally four markers were placed on the cart to track its motion during the pushing and pulling asks. A subject calibration trial was then performed.

ii) The participant then performed the dynamic cart pushing/pulling trials. Each participant performed eight (2 techniques × 2 weights × 2 repetitions) experimental trials. The duration of an individual trial was approximately 20-

25 seconds with a rest period of 5-10 seconds between the trials. All the trials were collected on the same day for each participant.

iii) Kinematic and GRF data were exported in the C3D format from the Vicon Nexus software. The C3D data were imported in the AnyBody modeling platform using AnyScript programming language. A full body biomechanical model provided by the AnyBody modeling system was modified by creating thirty-nine nodes on it to represent approximate locations of the reflective markers on the body model. A mechanical model of cart was created in the AnyBody modeling platform.

iv) Once all the data were imported in the AnyBody modeling platform, the generic full body musculoskeletal model was scaled to anthropometrically match each individual participant. Participant's body mass, height and segmental lengths were coded to adjust the bone sizes and marker locations on the model.

v) Parameter optimization routine was then performed. Using this routine, the system performs an optimization of the model to fit the recorded C3D data. This was much more than simply making the model follow the marker trajectories; it also optimized the model parameters such as segmental lengths and marker placements, based on the recorded data. The optimized values of the variable parameters, consisting of updated anthropometrical segmental lengths, updated marker locations and the kinematic movement, were saved on text files for later use.

vi) Once all the parameters were optimized, inverse dynamics operation was performed. This analysis loaded the optimized model parameters that were saved previously; if necessary, it also performed calibration movements to adjust the tendon lengths to the lengths of the bones; and finally executed an inverse dynamic analysis to determine forces in the system. Figure 1 shows the human participant performing the pushing and pulling trials and the corresponding musculoskeletal model.

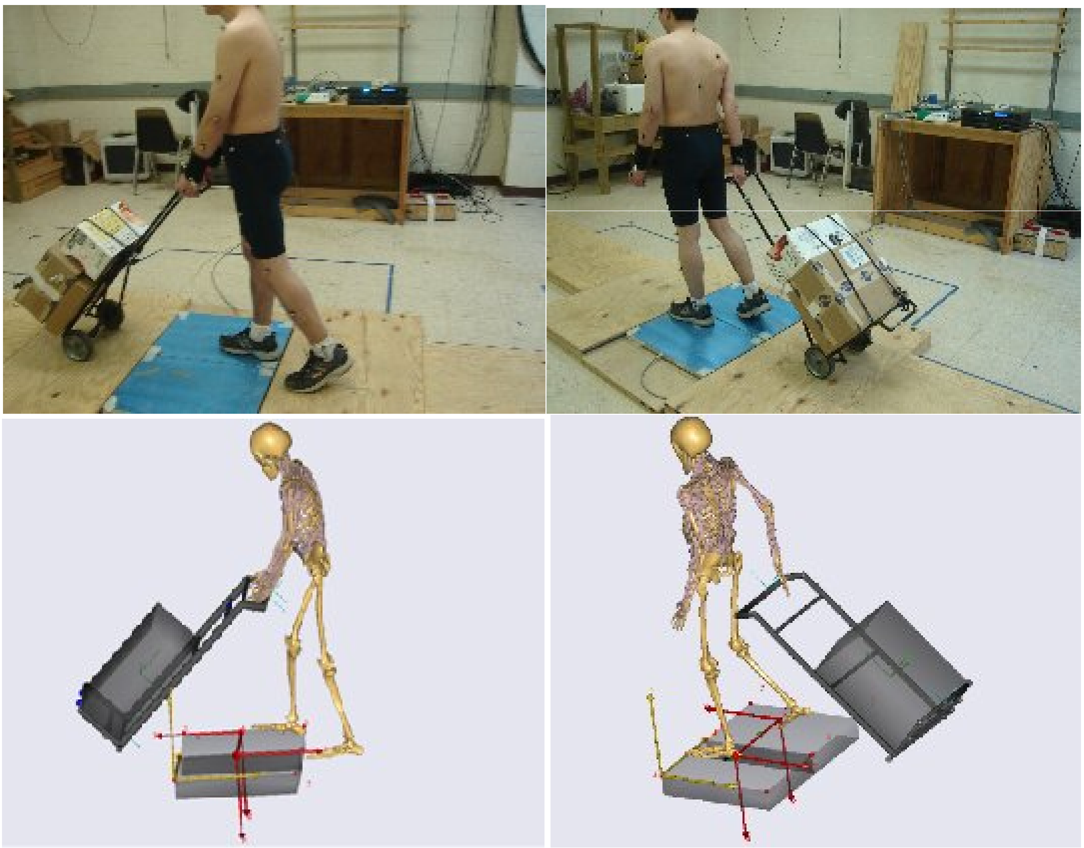

Figure 1: Human participant performing the pushing and pulling trials and the corresponding biomechanical model used for quantifying the musculoskeletal loading

2.6 Statistical Analysis

A two-way analysis of variance (ANOVA) model with repeated measures was used for performing statistical analysis. Statistical software (Statistix 9.0, Analytical Software, FL, USA) was used in the present study. Pushing/pulling techniques and the loads transferred were treated as the within subject variables. The significance level was set at 5%.

3. Results

3.1 Low Back Loading

The technique used for performing the pushing and pulling tasks had no significant effect on the loading of the L5S1 joint. In general, compressive (proximal-distal, PD) and anterior-posterior (AP) shear forces were found to be higher during two-handed forward pushing than one-handed forward pulling (Table 1, Figure 2). Medio-lateral (ML) shear forces were found to be negligible during both the pushing and pulling exertions. The increase in the amount of weight transferred from 25 kg to 35 kg increased the average compression force at the L5S1 joint by 17.7% and the AP shear forces by 16.8%, respectively. However, this increase was statistically insignificant.

Table 1: The loading of low back and shoulder joints (N) expressed in terms of mean reaction forces (SD)

Joint	Force	Push		Pull	
		25 kg	35 kg	25 kg	35 kg
Low back (L5S1 joint)	ML	10.28 (5.94)	13.21 (6.29)	11.49 (8.41)	11.81 (7.05)
	PD	821.36 (316.04)	945.64 (396.10)	696.91 (96.44)	841.11 (157.27)
	AP	156.91 (82.10)	181.67 (86.62)	110.59 (18.72)	130.72 (28.75)
Sternoclavicular (SC joint)	ML	59.94 (11.12)	74.58 (23.44)	44.91 (7.17)	49.84 (13.49)
	IS	20.46 (15.95)	26.88 (17.22)	34.73 (4.95)	**47.69**[a] (12.05)
	AP	12.46 (4.44)	16.71 (6.77)	**54.13**[b] (11.68)	**71.32**[a,b] (15.63)
Acromioclavicular (AC joint)	ML	42.49 (12.52)	55.64 (24.11)	**396.32**[b] (64.17)	**516.89**[a,b] (116.61)
	IS	109.58 (64.44)	145.96 (76.53)	**487.58**[b] (72.61)	**644.11**[a,b] (145.98)
	AP	63.25 (14.63)	76.59 (26.61)	**216.31**[b] (31.62)	**279.15**[a,b] (67.58)
Glenohumeral (GH joint)	DIS	180.96 (63.33)	215.89 (88.38)	**950.36**[b] (114.59)	**1197.50**[a,b] (238.55)
	IS	72.89 (43.73)	88.02 (45.44)	**315.40**[b] (81.92)	**438.72**[a,b] (121.41)
	AP	37.76 (19.62)	41.90 (21.23)	**214.31**[b] (32.33)	**274.48**[a,b] (44.80)

[a] Significant difference between 25 kg and 35 kg using the same technique
[b] Significant difference between two techniques at the same load level

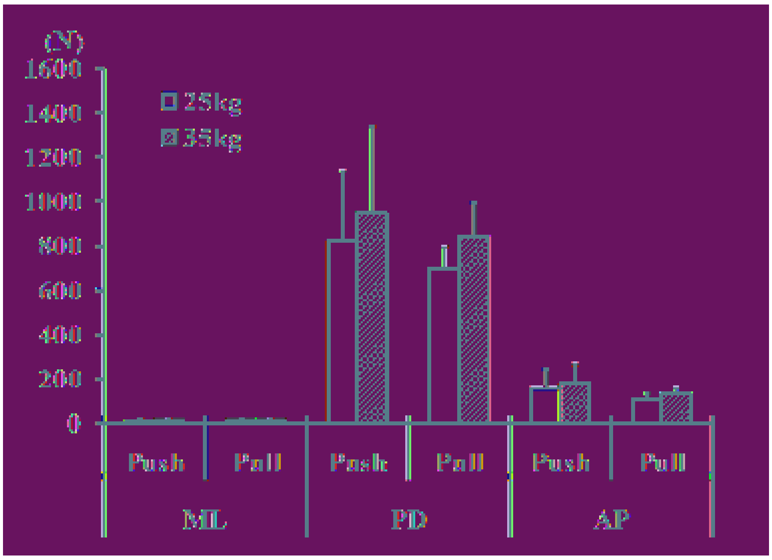

Figure 2: Loading at L5S1 joint during dynamic cart pushing/pulling tasks

3.2 Shoulder Joint Loading

3.2.1 Sternoclavicular joint

Significant differences were observed in the loading of the sternoclavicular joint with the change in the technique (Table 1, Figure 3(a)). Loading of sternoclavicular joint during one-handed pulling in the AP direction was significantly higher by 330% than two-handed pushing. However, the loading in the ML direction was significantly higher by 42.0% during two-handed pushing than one-handed pulling. An increase in the load from 25 kg to 35 kg increased the loading of the sternoclavicular joint in infero-superior (IS) and AP directions by 35.1% and 32.2%, respectively. This increase was statistically significant. Forces in the ML direction increased by 18.7%, however this increase was statistically insignificant.

3.2.2 Acromioclavicular joint

One-handed forward pulling technique imposed significantly higher forces at the acromioclavicular joint than two-handed forward pushing during cart transferring tasks (Table 1, Figure 3(b)). During one-handed forward pulling, loading in the ML, IS, AP directions were higher than two-handed forward pushing by 831%, 343%, and 254%, respectively. Increase in the load from 25 kg to 35 kg increased the loading of the acromioclavicular joint in the ML, IS, AP directions by 30.5%, 32.2%, and 27.2%, respectively. This increase was statistically significant.

3.2.3 Glenohumeral joint

Loading of the glenohumeral joint was significantly affected by the pushing/pulling technique used by the participants (Table 1, Figure 3(c)). Distraction (DIS) forces at glenohumeral joint and the forces in the IS, AP directions during the one-handed pulling were higher by 441%, 369%, and 514%, respectively than during the two-handed pushing. Transferring load mass of 25 kg to 35 kg increased the DIS, IS, AP forces at the glenohumeral joint by 24.9%, 35.7%, 25.5%, respectively. This increase in the forces with the increase in the load transferred was statistically significant.

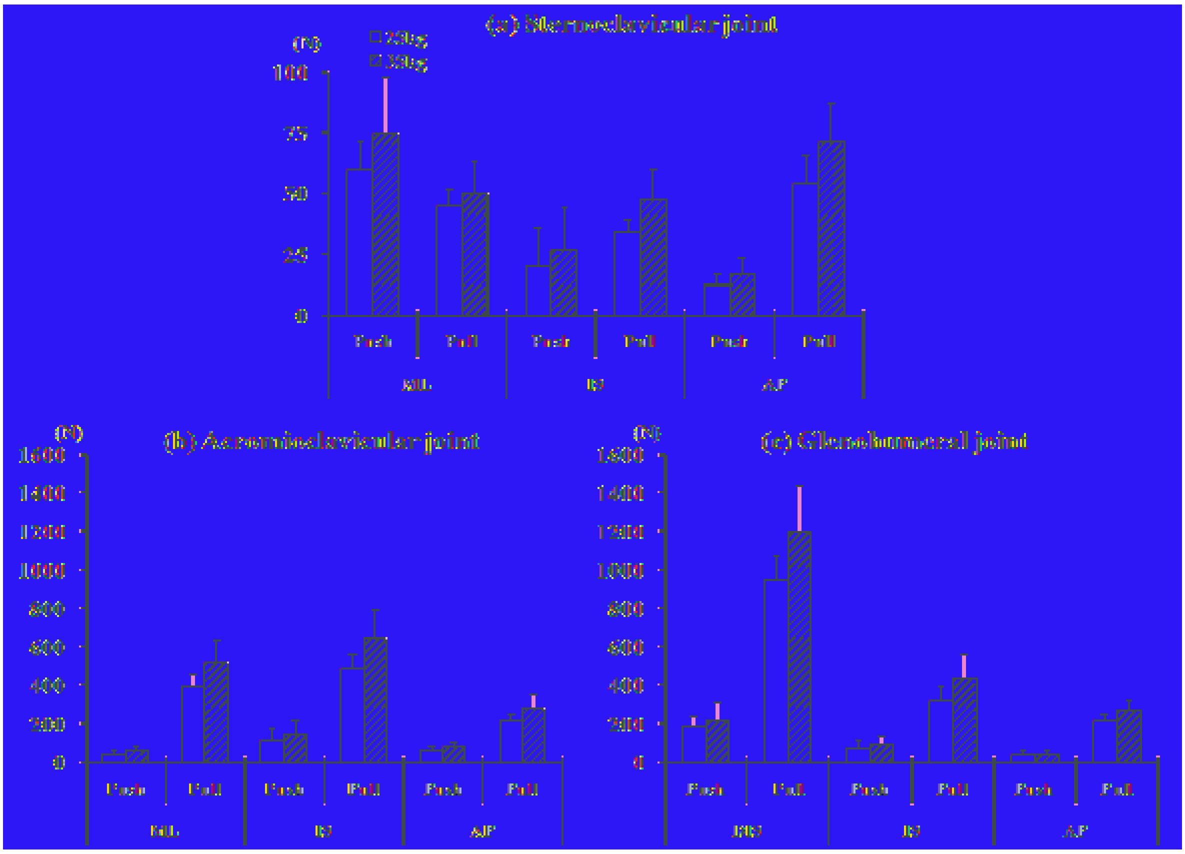

Figure 3: Loading at shoulder joints during dynamic cart pushing/pulling tasks

4. Discussion

In this study, dynamic cart pushing and pulling exertions were studied to evaluate their effects on the loading of low back and shoulder joints. The results of this study demonstrated that neither technique nor load transferred had a significant effect on the loading of the L5S1 joint. Among the shoulder joints, the loading of the sternoclavicular, acromioclavicular, and glenohumeral joints were affected by the technique as well as the load transferred. This finding corroborated well with previous study of Laursen and Schibye [31] which reported that the weight transferred (12.5, 25, and 50 kg) affected the load on the shoulders but not the load on the lumbar spine at the L4L5 level. The lumbar spine compression force was reported to be below 1800 N and the shear force was below 200 N in all situations. The results of the present study showed that the lumbosacral joint loading at the L5S1 level was below 1400 N and the shear force was also below 270 N in all situations.

To our knowledge no previous study has reported 3-D loading of all three shoulder joints during dynamic pushing and pulling tasks. Among the three shoulder joints, the loading of the glenohumeral and acromioclavicular joints were found to be the most sensitive to the change in the technique. 3-D loading of these joints was found to be significantly higher during one-handed pulling than two-handed pushing. For the sternoclavicular joint, the loading in the ML direction was higher during two-handed pushing than one-handed pulling. In the remaining two directions (IS and AP), higher loading during one-handed pulling than two-handed pushing was found. Hoozemans et al. [32] argued that use of one or two hands was an important factor to acknowledge with regard to lower back and shoulder loading during dynamic pushing/pulling tasks. Overall, bilateral exertions were preferable to unilateral ones in minimizing the risk of injuries [11] and enhancing performance. The results of this study indicated that the overall loading of the shoulder during one-handed pulling was 3.6 times higher than two-handed pushing. Fothergill et al. [33] reported that during pushing/pulling exertions, stresses on the shoulder joint during bilateral exertions were twice than during unilateral exertions. In summary, the present study confirmed that one-handed pulling causes higher loading of the shoulder region than two-handed pushing.

Complaints involving lower back and shoulder MSDs due to work-related pushing/pulling activities are evident in the epidemiological literature. However, there is no definitive evidence to suggest a causal relationship because most the existing investigations have been cross-sectional in nature. The results of the present study indicate that the loading of the shoulder region is more responsive to weight transferred and the technique than the low back region during pushing/pulling exertions, further indicating a possibility of higher risk of shoulder MSDs during such exertions than low back MSDs.

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