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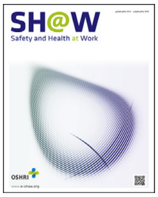

Review Article

Human Body Mechanics of Pushing and Pulling: Analyzing the Factors of Task-related Strain on the Musculoskeletal System

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ABSTRACT

The purpose of this review is to name and describe the important factors of musculoskeletal strain originating from pushing and pulling tasks such as cart handling that are commonly found in industrial contexts. A literature database search was performed using the research platform Web of Science. For a study to be included in this review differences in measured or calculated strain had to be investigated with regard to: (1) cart weight/ load; (2) handle position and design; (3) exerted forces; (4) handling task (push and pull); or (5) task experience. Thirteen studies met the inclusion criteria and proved to be of adequate methodological quality by the standards of the Alberta Heritage Foundation for Medical Research. External load or cart weight proved to be the most influential factor of strain. The ideal handle positions ranged from hip to shoulder height and were dependent on the strain factor that was focused on as well as the handling task. Furthermore, task experience and subsequently handling technique were also key to reducing strain. Workplace settings that regularly involve pushing and pulling should be checked for potential improvements with regards to lower weight of the loaded handling device, handle design, and good practice guidelines to further reduce musculoskeletal disease prevalence.

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1. Introduction

Industrial workspaces have mostly been redesigned to replace the carrying of objects by tasks that require pushing or pulling [1]. According to literature, these tasks could end up leading to the development of musculoskeletal disorders (MSDs), presumably due to high loads and/or frequent task repetition [2,3]. A current analysis in the automotive supply sector has shown that about 10% of all working processes involve pushing and pulling on a regular and repetitive basis, with a great share (41.2%) requiring the manipulation of objects with total masses between 200 kg and 1,000 kg [4].

When operating these cart masses, which have to be maneuvered manually by hand, the exerted forces create a joint torque, joint compression, and joint shear [5]. The hurdles in sufficiently designing study protocols to evaluate realistic manual handling activities might result in the lack of guidelines for workplace or handle design in this context. Therefore the hazards of handling heavy loads manually have not been contained properly to date [6]. Accordingly, "best practice" recommendations on how to ergonomically operate carts and create a functional grip design are still insufficient.

In the challenge to reduce MSD prevalence research has focused on how pushing and pulling task intensity is related to these internal strain factors at injury-prone body locations such as the knees, the shoulders, and the lower back [7]. The task intensity is commonly quantified by measuring muscle activation response [electromyogram (EMG)] and hand or ground forces and is dependent on external parameters such as the mass of the handled object, wheel and floor properties, and on the configuration of the hand—object interface (mostly a set of handles attached to the object). Likewise, to assess biomechanical load these parameters have to be quantified in terms of intensity, duration, and frequency. Handle configurations like different handle heights, influence how forces can be applied to the cart by the person maneuvering it. Consequently, handles potentially allow for the reduction of task

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Table 1
Search stages and number of papers retained after each stage

Search stage	Papers retained Web of Science
1. “EMG” or “force” or “mechanical load” or “kinematic”	2,839,954
2. “Cart” or “trolley” or “carriage” or “handle”	1,153,084
3. “Pushing” and “pulling” or “push” and “pull”	58,990
4. Combination of 1, 2, and 3	1,012
5. Refined by document type “article” or “review”	144
6. Retained after reading title or/and abstract	23
7. Total number included after reading the whole paper	13

EMG, electromyogram.

intensities and internal biomechanical strain as shown in a reduction of required forces at the hands which lead to a decreased muscle activation response between comparable tasks. The studies reported in this review focus on the interactions between task intensity, external parameters (object and environment), and internal strain, e.g., as a result of the impact of the cart weight and resulting forces on body segments or muscles.

Conclusions from task intensity on biomechanical strain are drawn by body segment models that calculate estimates of torques, compressions, and shear forces [2,8–13]. Some studies showed results that have been derived psychophysically by using the concept of maximum acceptable force (MAF) to quantify global physical strain [2,3,8,14]. The values for an acceptable force level are obtained when the individuals’ perception of the task (acceptable strain) meets specific additional information (e.g., single task performed once in an 8-hour shift) [14]. The Borg scale for the received perception of exertion (RPE) has been used to determine the physiological demand in push—pull tasks [14,15].

To the authors’ knowledge there is no systematic literature review that summarizes the existing data on push–pull task-related biomechanical strain factors such as joint torque, compressive and shear forces, and their influencing variables like specific muscle activity, body positioning, direction of exertion, and workspace environment. A comprehensive review by Garg et al [16] failed to address important factors like handle orientation etc. Moreover, it did not meet the criteria of a systematic review.

The objective of this review is to systemize results from research papers that have investigated biomechanical strain in pushing and pulling tasks. Important factors that constitute strain on the musculoskeletal system will be reported and described. Additionally, by synthesizing the results, recommendations on workspace or handle design can be developed.

2. Materials and methods

The systematic literature database search was performed using the Web of Science Core Collection, Current Contents Connect, Medline, and Biosis Zitation Index (1864–2016, Week 2). Search stages and the number of papers retained in each database and search stage as well as the combination of keywords used for the query are listed in Table 1.

2.1. Selection criteria

The following methodological filters were applied: (1) testing of pushing as well as pulling as a primary handling task; and (2) measuring either EMG and/or hand forces and/or kinetic and/or kinematic data. Studies were included when at least one of the following factors that influence the level of biomechanical and physiological demand during pushing and pulling tasks was investigated:

(1) Cart weight/load
(2) Handle position and design
(3) Exerted forces
(4) Handling task: push and pull
(5) Task experience

After screening the title and abstract for the inclusion criteria a total of 24 studies were retained. Following a more detailed assessment one study [17] was excluded due to similar content to a second study by the same author [2] and another one because it primarily focused on sex differences [18]. There were studies excluded for not meeting the inclusion criteria (Table 5) [5,17–25]. Thirteen studies were retained after reading the whole paper and submitted to assessment of their methodological quality (Table 1).

2.2. Quality assessment

The set of Standard Quality Assessment Criteria (SQAC) for evaluating primary research papers proposed by the Alberta Heritage Foundation for Medical Research was used to assess the methodological quality of the studies included in this review. The quality criteria, as described in SQAC, were: (1) sufficient description of the question/objective; (2) appropriate study design; (3) appropriate method of participant selection or source of information/input variables; (4) sufficient description of participant characteristics; (5) description of interventional and random allocation; (6) report of means of assessment with outcome measures well defined and robust to measurement/misclassification bias; (7) appropriate sample size; (8) appropriate analytic methods and method description; (9) report of estimate of variance in main results; (10) control for confounding; (11) sufficiently detailed report of results; and (12) conclusions supported by the results.

Participant selection (3) was verified by comparing the sample with the conclusions drawn from the experimental results. When the sample consisted of nonprofessionals but results were projected on a professional population this was considered a source of error. Professionals might have employed more efficient strategies in the experimental situation that would have altered the results. Only random allocation was assessed (5), as no interventions were carried out in the present studies. Appropriate sample size (7) evaluation was based on an exemplary calculation using G*Power software (Heinrich Heine University, Dusseldorf, Germany, Version: 3.1.9.2). The repeated measures analysis of variance used in nine out of 13 studies requires a sample size of at least 36 participants (critical $F = 4.13$) when an effect size $f = 0.5$ is assumed (α error: 0.05; power: 0.95) provided the study includes at least two groups with four measurements. A full point for appropriate sample size was given when either an *a priori* calculation of sample size had been described or the sample size was at least 36 (for analysis of variance). Based on the analytic methods employed (8) important statistical values (F, t, and p values) had to be included to obtain a full quality score. Each of the authors performed the assessment independently and the results presented in Table 2 were concurred on. Each criteria ($n = 12$), when complied, was given one point. Points were added up and resulted in the quality score. The necessary score for a study of high quality was defined to be ≥ 10 out of 12 (75%) and $\geq$ 6–9 for standard quality according to the SQAC. No point was given if general remarks had to be made (indicated by brackets; Table 2).

3. Results

Based on the quality score five studies [8,9,13,26,28] were classified as high quality and eight [2,10–12,14,27,29,30] as standard quality. Certain quality criteria were missing repeatedly or did not

Table 2
Quality scores of the included studies and remarks

Study	Quality criteria*												Quality score	Remark
	a	b	c	d	e	h	i	j	k	l	m	n		
Al-Eisawi et al 1999 [8]	x	x	(x)	x	x	x	(x)	x	x	x	x	x	10	c: nonprofessional participants; i: small sample size
Backhaus et al 2012 [2]	x	x	x	x	—	(x)	x	(x)	(x)	x	x	x	8	h: definition of initial forces problematic; j: no description; k: very few details
Bennett et al 2011 [26]	x	x	(x)	x	x	x	x	x	(x)	x	x	x	10	c: nonprofessional subjects (but "extensive habituation"); k: few details
Boocock et al 2006 [14]	x	x	(x)	x	—	x	(x)	x	x	x	x	x	9	c: nonprofessional participants (but "accustomed to manual handling work"); i: small sample size
Boyer et al 2012 [28]	x	x	x	x	—	x	(x)	x	x	x	x	x	10	i: small sample size
Di Domizio and Keir 2010 [27]	x	x	—	x	—	x	(x)	x	x	x	x	x	9	i: small sample size
Hoffman et al 2011 [29]	x	x	x	x	x	x	(x)	x	(x)	(x)	x	x	9	l: participants given "as much rest as needed"; i: small sample size; k: few details
Hoozemans et al 2004 [13]	x	x	x	x	x	x	x	x	x	—	x	x	11	
Kao et al 2015 [30]	x	x	(x)	x	—	(x)	(x)	x	x	—	(x)	x	6	C: nonprofessional participants; i: small sample size; m: no effect size
Lee et al 1991 [12]	x	x	(x)	x	—	(x)	(x)	x	x	x	x	x	8	c: nonprofessional participants; h: pull posture not specified, simple two-dimensional kinematic analysis; i: small sample size
Lett and McGill 2006 [11]	x	x	x	(x)	x	x	(x)	x	x	—	x	x	9	d: age not specified; i: small sample size
Schibye et al 2001 [10]	x	x	x	x	—	x	(x)	x	—	—	x	x	8	i: small sample size
Xu Xu et al 2013 [9]	x	x	x	x	x	(x)	(x)	x	(x)	x	x	x	10	h: handle height not specified; i: small sample size; k: few details

*x, yes; (x), was partially done, general remarks; —, no/unclear; free fields, not relevant.
a, sufficient description of question/objective; b, appropriate study design; c, appropriate method of participant selection or source of information/input variables; d, sufficient description of patient characteristics; e, description of interventional and random allocation; h, report of means of assessment with outcome measures well defined and robust to measurement/misclassification bias; I, appropriate sample size; j, appropriate analytic methods and method description; k, report of estimate of variance in main results; l, control for confounding; m, sufficiently detailed report of results; n, conclusions supported by the results.

match to full extent. Seven out of 13 studies did not employ or did not describe random allocation of their test setting [2,10,12,14,27,28,30]. The control of confounding variables (e.g., floor friction, uniformed by wearing standardized shoes) that might have influenced the measurements was not or only insufficiently described in four studies [10,11,13,29]. The results from statistical analysis might have been biased by small sample sizes in 10 studies [8–12,14,27–30] according to the standard described for this review (see Methods section).

Five of the studies had nonprofessional participants perform push–pull tasks usually executed by professionals only and the results were projected on general industrial situations [8,12,14,26,30]. There was no information on the participant selection procedure available except for one study [27]. Pulling direction was not specified in two of the included studies [8,12] and one defined initial and sustained forces based on the percentile of exerted force instead of the respective movement phase [2]. In Table 3 included studies are listed to provide an overview. Classification has been done with regard to: (1) study aim; (2) method of data collection; (3) handling tested (push–pull); (4) experimental arrangement; (5) controlling of confounding factors.

The studies listed in Table 3 were heterogeneous in: (1) sample size (ranging from six to 36 participants); (2) the handling task: 11 studies tested dynamic handling tasks, one tested isometric handling tasks, and one tested both; (3) the experimental setup: 10 experiments were conducted using a cart or cart-like device, one using a cable pulley, and two worked with a static device; (4) the source of data collection: hand forces, EMG, and kinematic data were collected by two research groups: eight used two of these systems, while three studies were based on one source of data; (5) the model used to calculate joint strain: the number of linked segments simulated to describe the participants' movement kinematics ranged from five to 15; (6) the handle configuration: handle heights ranged from 0.1 m above head, shoulder, waist, and hip height to mid-thigh or knuckle height when they were set for each participant individually. In eight studies the handle was set at one or more fixed heights [9,10,12,14,26–28,30].

An overview of the results presented afterwards can be found listed by name of author in Table 4.

3.1. *Cart mass*

The total cart mass was reported to increase the exerted hand forces (EHF), lower back moment (LBM), shoulder moment, lower back compression force (LCF; L5–S1), shoulder compression force, and lower back shear force and therefore affected all dependent variables [11,13]. When moving a cart with greater mass the EHFs increase disproportionately to the nominal force needed to generate that movement [8]. Waste collectors handling the larger of two (1,100 L, 148 kg) containers considerably exceeded the proposed MAF of 186N for sustained EHFs. Here, task frequency was set at 1/min with a handling distance of 15 m and task duration of one 8-hour shift [2]. When manipulating a similar cart mass (181 kg), male participants did not exceed their level of MAF, whereas female participants were at the limits of their respective MAF. In this case the male population was stronger (isometric strength) than the female population compared with their respective averages [8]. All studies confirmed the assumption that reducing cart mass most significantly decreases strain on the musculoskeletal system [2,8–14,26–30].

3.2. *Handle position and design*

All authors found alterations in investigated parameters when operating at different handle heights and handle positions. EHF decreased with greater handle height but only for the heavier (181 kg) of two cart masses [8]. Net moments at the shoulder joint, as a term for mechanical load, were lower when pushing and pulling were performed at shoulder height [13]. Based on the measurement of spinal compression forces on the lower back, handles should be at waist level for pulling and shoulder level for pushing [11]. This result is supported with respect to pulling as LCFs were found to decrease with handle height regardless of handling posture [12]. Off-axis hand forces diminish when operating in a neutral forearm position (palms directed vertically upwards) which was interpreted as an indication of greater ease of task [27].

3.3. *Exerted forces*

Among calculations of the mechanical load on the lower back and shoulders only the maximum LBM showed a relatively high

Table 3
Characteristics of the included studies

Study	Participants, *N*, sex, age (M, SD)	Study aims	Collected data	Handling tested	Experimental arrangement	Confounding factors controlled for
Al-Eisawi et al 1999 [8]	*n* = 10; 5 (f)/ 5 (m) (np) Age (y): 28.4 ± 3.6 (m) 21.6 ±1.5 (f) Mass (kg): 91.8 ± 15.1 (m) 68.9 ± 8.7 (f)	Comparison of initial HF & postures to minimal (nominal) force and psychophysical push/pull limits	3D HF	bl pushing (bw) bl pulling	4-Wheeled cart (swiveling wheels at front) CM: 73/181 kg HH: knuckle, elbow, shoulder	CoF (floor) between 0.73 and 0.77 Cart wheels (orientated in direction of movement)
Backhaus et al 2012 [2]	*n* = 10 (m, p) Age (y): 42 ± 10 Mass (kg): 94 ± 14	Comparison of initial and sustained hand forces and body postures	3D HF motion analysis system (CUELA)	bl pushing bw bl pulling fw ul pulling	2- and 4-Wheeled waste-containers 120 L/ 240 L/1,100 L; straight, inclination & corners	Walking velocity
Bennett et al 2011 [26]	*n* = 36 (m) Age (y): 21 ± 2 Mass (kg): 77 ± 10	Investigation of MA responses & risk of injury	EMG ul UB/LB loaded versus unloaded (walking fw/bw)	bl pushing fw ul pulling bw bl pulling	3-Wheeled pallet jack 10 m straight CM: 250/500 kg moved	Identical footwear, walking speed (0.4–0.5 m/s) Fatigue effects
Boocock et al 2006 [14]	*n* = 8 (m) Age (y): 35.1 ± 7.7 Mass (kg): 73.9 ± 9.1	Determination of changes in kinematics and kinetics with floor friction; determine MAF	3D GF+ HF (50 Hz) 3D postures (50 Hz) during initial force exertions	bl pushing bw bl pulling	4-Wheeled trolley on rails 3 m straight line Fix HH (106 cm)	Fatigue effects Identical footwear
Boyer et al 2012 [28]	*n* = 24 (f) *n* = 12 (p) Age (y): 45.8 ± 8.7 Mass (kg): 76.9 ± 18.4 *n* = 10 (np) Age (y): 21.7 ± 1.3 Mass (kg): 60.4 ± 8.6	Analysis of hand force exertion patterns of experienced nurses and nursing students during dynamic cart pushing tasks	3D motion analysis of cart 3D HF (100 Hz)	fw bl pushing (initial, sustained, turning, stopping)	4-Wheeled cart CM: 120 kg	CoF (floor) between 0.45 and 0.24 Hand dominance Lane congestion
Di Domizio and Keir 2010 [27]	*n* = 12; 6 (m)/6 (f) Age (y): 25.8 ± 2.5 Mass (kg): 83.8 ± 10.0 (m) 62.5 ± 12.0 (f)	Evaluation of effects of gripping on MA and HF with pronated/neutral/ supinated forearm	EMG ul 8 UB muscles; hand grip force + 3D HF	Standing ul (dominant hand) isometric push/ pull + hand grip	Static, hand dynamometer	
Hoffman et al 2011 [29]	*n* = 19; 9 (m)/10 (f) Age (y): median 21 BMI (kg/m^2): median 23	Quantification & modulation of actual HF to required nominal horizontal and vertical HF	3D kinematics (50 Hz) 3D GF & HF	Standing bl isometric push/ pull and push (upwards)	Static hand dynamometer HH: mid-thigh, elbow, 0.1 m above head; 25%, 50%, 75%, 100% of max force exertion capability	
Hoozemans et al 2004 [13]	*n* = 7 (m) Age (y): 33.7 ± 6.2 Mass (kg): 76.2 ± 18.1	Quantification of ML (lower back & shoulders) relation between initial and sustained HF & ML	3D HF 3D kinematics (50 Hz) EMG (8 muscles; bl)	ul/bl pushing bw ul/bl pulling	4-Wheeled cart 4 m straight CM: 85 kg, 135 kg, or 320 kg HH: Sh & Hh	
Kao et al 2015 [30]	*n* =10 (f) Age (y): 22.4 ± 2.24 Mass (kg): 52.9 ± 4.40 Height (cm): 161.7 ± 2.65	Effects of direction of exertion (pushing, pulling) and load placement on muscle activity and perceived exertion	EMG Borg CR-10-Scale (RPE)	bl pushing bl pulling	4-Wheeled nursing cart HH: waist Mass: 75 kg Gait pace: 80 steps/min	CoF Sole-Floor: < 0.5 Gait pace: 80 steps/min Load placement
Lee et al 1991 [12]	*n* = 6; 4 (m)/2 (f) Age (y): 23.4 (20–30) Mass (kg): 50–80	Effect of handle height on ML (lower back)	Simple 2D kinematics HF (horizontal)	bl pushing (bw) bl pulling	Handlebar on rails HF: 98N, 196N, and 294N HH: 0.66 m, 1.09 m, 1.52 m Speed: 1.8/3.6 km/h	Identical footwear (CoF ∼0.6)
Lett and McGill 2006 [11]	*n* = 9 (m; 4 p, 5 np) Age (y): n.a. Mass (kg): 74.7 ± 12	Effect of push/pull activities on ML (lower back)	3D kinematics EMG HF (horizontal)	Isometric & dynamic bl pushing (bw) bl pulling	Cable pulley system HH: shoulder/waist Loads: 44.5N, 222.4N, 400.5N	
Schibye et al 2001 [10]	*n* = 7 (m) Age (y): 42 (36–46) Mass (kg): 77 (70–91)	Comparison of ML in lift and push/pull tasks; relation: object (mass) & ext. forces & mech. load	3D HF 2D kinematics	fw bl pushing fw bl pulling lifting & carrying	2-Wheeled container 10 m straight CM: 25/50 kg HH: 0.85 m	
Xu Xu et al 2013 [9]	*n* = 10 (f ;p) Age (y): 47.1 ± 8.8 Mass (kg): 76.1 ± 19.9 *n* = 10 (f ;semi-p) Age (y): 21.7 ± 1.4 Mass (kg): 60.2 ± 9.0	Effects of lane congestion, cart load stability, floor surface friction on shoulder joint moment and elevation angle	3D kinematics 3D push/pull forces	fw bl pushing	4-Wheeled medicine cart Straight tracks and right-angle corners Mass: 120 kg	Identical footwear, constant hand positions on cart

3D, three dimensional; bl, bilateral; BMI, body mass index; bw, backward; CM, cart mass; CoF coefficient of friction; EMG, electromyogram, (f), female; fw, forward; GF, ground force; HF, hand force; HH, handle height; Hh/Sh, hip height/shoulder height; LB, lower body; M, mean; MA, muscle activity; MAF, maximum acceptable force; (m), male; ML, mechanical load (collected data): n.a., not applicable; np, nonprofessionals; p, professionals; SD, standard deviation; UB, upper body; ul, unilateral.

Table 4
Overview of results

Study	Models used to calculate strain	Strain (other than direct measurement)	Observed strain on human body, especially mechanical load on lower back and shoulders, with regards to: (1) cart weight/load; (2) handle position and design; (3) exerted forces; (4) handling task: push/pull/turning; (5) task experience
Al-Eisawi et al 1999 [8]	n.a.	MAF	(2) EHF ↓ with ↑ HH (3) influence of task related factors on EHF > participant-related factors (strength, sex) (3), (1) difference between EHF and required horizontal force ↑ with cart load (4) comparable EHF for pushing and pulling
Backhaus et al 2012 [2]	n.a.	LCF, MAF	(3) proposed MAF-limit (Mital and Ramakrishan, 1999) exceeded considerably (1,100 L container)
Bennett et al 2011 [26]	n.a.	n.a.	(4) pushing elicited lowest activation response (upper body) (4) two handed pulling with majority of highest activation responses (upper body)
Boocock et al 2006 [14]	n.a.	MAF	(3) no effect of floor friction on MAF (3) no difference in EGF between floor frictions, but ↑ horizontal GF with ↑ floor friction and ↑ vertical GF with ↓ floor friction (3) no difference in EHF between floor frictions, but ↑ vertical downward HF when pushing + ↑ upward HF when pulling at low floor friction (3) ↑ correlation of MAF to horizontal GF than to horizontal HF (4) ↑ flexion at lower back when pulling ↑ RPE for pushing than pulling
Boyer et al 2012 [28]	n.a.	EHF	(3) (5) EHF ↑ with longer time on the job, significant ↓ of EHF in high precison control (4) highest EHF while turning on carpet
Di Domizio and Keir 2010 [27]	n.a.	n.a.	(2), (5) highest wrist extensor muscle activity when pushing/pulling in pronated forearm posture (2), (5) greater ease of task (minimal off-axis forces) when pushing/pulling with neutral forearm posture
Hoffman et al 2011 [29]	n.a	n.a.	(4) vertical off-axis forces avg. 52% of required on-axis force during pulling and 32% during pushing
Hoozemans et al 2004 [13]	Linked upper body 5-segment quasi-dynamic model (low back) & dynamic 3D model (SHM & SCF) EMG driven distribution model (LCF and LSF)	LBM, SHM, LCF (L5−S1), SCF, LSF	(1) only cart weight affected each of dependent variables significantly (1), (2) keep cart weight ↓ and push/ pull at shoulder height (3) relatively high correlation between initial forces and maximum LBM General: predicted maximum compressive forces at shoulder joint below recommended NIOSH limit of 3,400N (NIOSH 1981)
Kao et al 2015 [30]	n.a.	RPE	(1) load placement close to participant ↓ EMG activity (4) pushing tasks caused ↓ RPE than pulling tasks (4) pushing tasks caused ↓ EMG activity than pulling tasks
Lee et al 1991 [12]	11-Link dynamic biomechanical model	LCF (L5−S1)	(4) LBM posture dependent (4) pulling tasks caused ↑ LCF than pushing, regardless of HH and HF (4) pulling LCF ↓ with HH
Lett and McGill 2006 [11]	15-Segment link model (estimate muscle force, stiffness and stability) Spine stability analysis model	LBM (L4−L5) LCF LSF Stability index	(1) LBM and LCF ↑ with load (2) optimal HH: shoulder level (pushing) & waist level (pulling) (3) HF ↑ for pushing than pulling (4) pushing and pulling techniques influenced all mechanical spine parameters (4) pulling creates ↓ LBM/LCF than pushing under same conditions (6) LCF & EMG profile ↓ with task experience
Schibye et al 2001 [10]	Quasi-static 2D link segment model	LBM, SHM, LCF (L4−L5), LSF	(3) significant correlation between L4/L5 compression & horizontal external force, but none for torque (4) compression force L4/L5 rather small in all situations, but always ↑ during pulling than pushing
Xu Xu et al 2013 [9]	Full body 3D dynamic linked segment model	SHM	(1) ↓ peak SHM in all phases of pushing with high cart load stability (4) ↑ peak SHM with high congestion level when turning (+33 %) max SHM likely during turning

Analyzed strain: ↑ higher, ↓ lower.
2D, two dimensional; 3D, three dimensional; EHF, exerted hand-force; EGF, exerted ground force; LBM, low back moment; LCF, low back compressive force; LSF, low back shear force; MAF, psychophysical concept of "maximum acceptable force"; n.a., not applicable; NIOSH, National Institute for Occupational Safety and Health; SCF, shoulder compressive force; SHM, shoulder moment; RPE, Borg's received perception of exertion.

Table 5
Excluded papers

Excluded papers	Reason for exclusion
Backhaus C, Post M, Jubt K, Ellegast R, Felten C, Hedtmann J. Handkraftmessung beim Bewegen von zwei- und vierrädrigen Müllgroßbehältern. GfA (Hrsg.) Chancen durch Arbeits-, Produkt- und Systemgestaltung; 2013. p. 241–4. [in German].	Similar study of same author included in review
De Looze M, Van Greuningen K, Rebel J, Kingma I, Kuijer P. Force direction and physical load in dynamic pushing and pulling. Ergonomics 2000;43:377–90.	Only sustained forces
Gite L, Yadav B. Optimum handle height for a push-pull type manually-operated dryland weeder. Ergonomics 1990;331487–94.	Walking on treadmill while handling device
Homminga J, Lehr AM, Meijer GJ, Janssen MM, Schlösser TP, Verkerke GJ, Castelein RM. Posteriorly directed shear loads and disc degeneration affect the torsional stiffness of spinal motion segments. Spine (Phila Pa 1976) 2013;38:E1313–9.	Computer simulation
Sandfeld J, Rosgaard C, Jensen B. L4–L5 compression and anterior/posterior joint shear forces in cabin attendants during the initial push/pull actions of airplane meal carts. Ergonomics 2014;45:1067–75.	Low cart weight
Jin SN, Armstrong TJ. Biomechanical analysis for handle stability during maximum push and pull exertions, Ergonomics 2009;52:1568–75.	Too distinct from dynamic cart pushing and pulling
Seo N, Armstrong T, Young J. Effects of handle orientation, gloves, handle friction and elbow posture on maximum horizontal pull and push forces. Ergonomics 2010;53:92–101.	Too distinct from dynamic cart pushing and pulling
Van Der Beek A, Kluver B, Frings-Dresen M, Hoozemans M. Gender differences in exerted forces and physiological load during pushing and pulling of wheeled cages by postal workers. Ergonomics 2000;43:269–81.	Grip positions not defined; special pull technique
Young J, Lin J, Chang C, McGorry R. The natural angle between the hand and handle and the effect of handle orientation on wrist radial/ulnar deviation during maximal push exertions. Ergonomics 2013;56:682–91.	Pulling not represented
Lin J, McGorry RW, Chang CC. Effects of handle orientation and between-handle distance on bi-manual isometric push strength. Appl Ergon 2012;43:664–70.	Pulling not represented

correlation to initial exerted forces [13]. Using fairly light containers (25/50 kg) another study reported no correlation between external forces and LBM but one for LCM instead [10]. With decreasing floor friction, greater vertical components of the EHF were measured while there was no difference between resulting EHFs [14]. One study found the MAF to be correlated higher to the exerted ground force (EGF) than to the EHF [14].

3.4. Handling: push–pull

In general, handling did not influence the level of EHF [2,8–10,12,13,26–29] and consequently task intensity. However, in one study EHFs were measured to be higher when pushing compared with pulling [11] and participants also reported a higher RPE for pushing [14]. Contradictory to this report, the lowest upper body muscle activation response in EMG data was found for pushing while two-handed pulling was the most taxing handling task [26]. Pushing also resulted in lower vertical off-axis forces averaging 32% of the required on-axis force (pulling: 53%) [29].

Pull exertions also induced up to twice as much LCF as pushing, regardless of handle height and hand forces [10]. Opposing results were been published in a study using a cable pulley system that concluded that LCF and LBM were smaller during pulling tasks [11]. With three exception [9,28,30], the experimental setups that were employed tested straight pushing and pulling only. Turning and transitions between movement directions were missing and consequently typical industrial manual handling tasks were not reflected properly.

3.5. Task experience

One of the selected studies examined the effects of task experience on biomechanical strain factors. The authors found that LCF and EMG profiles reduced with greater task experience (fire fighters vs. students) and considered work technique to be a dominant contributing factor to spinal loading and, by default, risk of injury [11]. When pushing, experienced workers create a hinge moment with the upper body in front of the base of support (leaning in against the weight). For pulling the hinge moment is created with the upper body behind the base of support (leaning back against the weight) and the line of action of the hand forces is directed through the lumbar spine to reduce moments as long as the handles are at waist level.

In summary, the physical demand of pushing and pulling tasks is most significantly dependent on the cart mass. There was no other single factor that clearly correlated to all measures of strain. For high frequency task repetition (single 15-m push/min or 15-m pull/min during one 8-hour shift) the MAF was equivalent to a cart mass of around 150 kg [2]. Net moments at the joints reduced when the handle was placed around the joint's height (e.g., shoulder height for shoulder joint) therefore causing the resulting force vector to pass near the joint axis. A decrease in floor friction led to greater vertical EHF components while the resulting hand forces showed no significant differences [14].

When considering handling, evidence supported either pushing or pulling depending on the strain factor the research was focused on. One study [30] reported higher muscle activation in general for pulling medicine carts as opposed to pushing.

Finally, participants with task experience and good work technique showed reduced spine loads and muscle activation profiles [11], although one study reported higher hand reaction forces for experienced nurses compared with nursing students while maneuvering a medicine cart [28].

4. Discussion

The aim of this review was to analyze high and standard quality research papers for results on biomechanical strain generated by manual handling tasks that involve pushing and pulling. Each study included in this review employed a different model when joint stress calculations were done. This might account for a part of the variation in results as different models are likely to produce slightly different outputs. As described earlier, numerous external factors determine task intensity and therefore potential strain. Accordingly, it was not surprising to find that studies focused on these factors heterogeneously. Amongst single factors like the handle height a wide range of settings in the same body region (hip height vs. waist height or elbow height) was used in the experimental setups. A standard definition of operating handle heights has to be agreed on to increase the comparability of future study results.

Small sample sizes are another methodological challenge that was met. Assumingly, certain economic restrictions (financial and time) in combination with extensive and time-consuming measurements necessary to obtain the required data have led to unsatisfying sample size selections. As small sample sizes must be considered as a potential source of error, the results are to be generalized with caution.

Furthermore, in using the Borg scale for the RPE to determine physiological demand in push–pull tasks, one has to consider that the scale of it is based on the linear increase of oxygen consumption and heart rate and therefore is likely to be best adapted to exertions involving a strong cardiovascular response.

4.1. *Reducing strain in push–pull tasks*

Overall, the mass of the object handled was the only factor which correlated with all reported biomechanical strain. Reducing cart mass will most likely lower the risk for MSDs. If the total cart masses cannot be changed but assumedly exceed tolerable limits, workplace (re-)design should involve the application of appropriate assisting devices when pushing and pulling are a regular demand.

Moreover, handle configuration and design were found to influence the majority of the investigated parameters [8,11–13,27]. However, the conclusions considering the handle configurations are more diverse in comparison to the cart mass [8,10]. To some degree different experimental setups and especially the equipment (Table 3) might have led to variations in handling biomechanics and consequently measurement outcomes. In conclusion, the study results indicate that there is no single advantageous handle position for pushing and pulling. However, there are individual optima for both handling techniques as well as for the parameters of biomechanical strain that were investigated [22,26,29]. Joint loads generally decrease if the resulting exerted forces are directed through or pass near the joint axis [22]. In consequence, handle design should allow switching between grip positions to meet this requirement and to distribute joint loads more evenly. This becomes even more important in cases where cart handling consists of numerous consecutive push–pull tasks in a variety of angles and directions.

Handles must be attached perpendicular to the force direction instead of parallel to it and must consist of a high friction surface material to allow optimal force application [27]. Unfortunately, different handle orientations in the plane perpendicular to force direction were not tested in the selected studies.

In order to reduce the cart's influence on physical demand, proper maintenance of the cart's wheels is recommended as the specific rolling resistance of the wheels plays a significant role [31] in the overall resistance provided by the cart. Furthermore, the right combination of surface and cart wheel material will also greatly influence wheel friction and therefore cart maneuverability.

Observations of EHFs or EGFs revealed that the correlations of joint loads are inconsistent [10,13]. One reason might be that the measurements of EHFs and EGFs are not comparable due to the fact that EHFs as opposed to EGFs increase disproportionately with cart mass [8]. Yet another possible explanation is the substantial influence of task experience and technique on joint load [11,28,30]. It remains unclear whether physical strain reduction is mainly due to handling technique or physiological qualities that differentiate professionals from nonprofessionals. While no relation to joint compression forces was found, psychophysically acceptable limits seem to be partly predictive of joint moments as they generate about 70% of the maximum joint moment tolerated by the most limiting joint in a given task [32]. However, due to the limited quality of the study by Fischer et al [32], this recommendation should be further investigated and proven.

As joint loads are not accessible to direct measurement, calculation models are used. The models employed to describe the kinetics of the handling movements were heterogeneous in the number of linked segments. This fact is likely to also contribute to variant results. For instance, Lett and colleagues [11] stated that pulling creates smaller LBM/LCF than pushing under the same conditions while opposing results were presented by Lee et al [12].

With regards to upper body EMG and the occurring off-axis force two-handed pushing must be considered less demanding than backward two-handed pulling [26].

4.2. *Limits for push–pull EHFs*

The included studies reported various recommendations for the maximum acceptable force during pushing and pulling. Frequency of task, task duration, and intensity, as well as population characteristics or the ambient temperature can influence the acceptable workload [3,32,33]. The proposed limits for maximum EHFs decrease from around 430N to less than 200N when task frequency augments from one per 8 hours to one per minute [2,34]. Other limits like the widely acknowledged value for maximum working L5–S1 intervertebral disc compression of 3,400N are usually meant to be valid for young and healthy men. It has been shown that, even in this population, these limits are consistently exceeded in push–pull task with heavy loads $>$ 225 kg [1]. These limits are bound to decrease when people get older or have a history of injury. Tasks with repetitive submaximum intensity are suspected to bear a substantial risk of developing MSDs as well but further research on this matter is needed [32]. With respect to the results from this review we conclude that limits for pushing and pulling must be considered in a set of workplace framework conditions. They should also consider the personal features of the people they are applied to.

5. Conclusions

Three distinct conclusions can be drawn from this review: (1) cart mass is certainly the most influential parameter as long as the cart's wheels are well maintained and do not present a barrier for manipulating the cart. It must thus to be given the appropriate consideration when designing workspace environment and tasks; (2) there is no single advantageous grip position and therefore handles should allow different hand positions between individual hip or waist and shoulder height; (3) task experience and technique are able to reduce at least some measures of biomechanical strain and therefore yield potential to reduce the risk of injury.

Technological resources will allow future research to run more elaborate biomechanical models that will describe human body mechanics more accurately. Experimental settings that not only include pushing/pulling straight on but also involve turning and changes of directions need to be designed to better reflect workspace environments [35]. Finally the effects of work experience and handling technique could not be differentiated from the present scientific data. For instance the question remains if the reduction in physical strain observed with work experience originates mainly from better handling techniques that could also be acquired in training sessions by nonexperienced workers.

Conflicts of interest

No conflicts of interest.

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