Hazards and Risks at Rotary Screen Printing (Part 5/6): Pushing and Pulling

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Abstract
Pushing and pulling-tasks were initially-intended to-replace manual-materials-handling, including lifting, and to-help to-reduce-stress on musculoskeletal-system. Pushing, pulling, and maneuvering materials- handling (MH)-equipment, however, *still* involve some of the-old-hazards (overexertion), while creating new-ones. This-study was focused on hazards and risks, associated with pushing and pulling-tasks, at finishing-department, of a-textile-mill. Document-analysis, questionnaire, and numerous-observations (*via* site-visits) were utilized, as main-instruments for the-study. In-compliance with the-ISO 20252:2006 (E), the-questionnaire was pre-tested, for validity and reliability; SPPS-17, version 22 was applied, to-compute the-Cronbach's coefficient. Descriptive-statistics was employed, to-analyze both; qualitative and quantitative-data. The-research targeted 12 printing-machine-operators; response-rate obtained (RR=92%). Majority of the-respondents (91%), indicated, that: repetitive-pushing and pulling-tasks were-conducted, daily; the-loads were heavy; moreover operators were *not* aware about the-actual-weigh, of a-particular load, so they just approximated; they also-pointed-out, that high-initial-forces were-required, to-get the-load moving; the-loads lacked good-handholds; and pushing and pulling-tasks were-conducted, in-confined spaces and/or narrow-doorways. 73% stated, that they performed more of pushing, than pulling-tasks. 64% indicated, that pushing and pulling involved: manoeuvring of the-load, into-position, or around-obstacles; some of the-MH-equipment was without brakes, making it difficult to-stop; and floors were, largely, uneven, damaged, and/or slippery. 45% claimed, that: occasionally, push or pull-movements involved high-speed and/or long-distances; MH-equipment (trolleys, carts), and floor-surfaces, were poorly maintained, cleaned and/or repaired; the-majority of MH-equipment was heavy, old, and hard to-steer; and that there was an-absence of the-suitable personal-protective-equipment, provided, and, hence, worn. In-addition to the-questionnaire, observation of different-pushing and pulling-practices, was conducted; one-illustrative-example of which, is presented, in-detail. Moreover, to-bring broader-perspective, the-following-aspects were covered: Pushing *vs.* pulling ongoing-debate; Pushing and Pulling Capability-Standards, Guidelines, and tools; Pushing and pulling-task phases and forces, involved; as-well-as relevant-factors/characteristics of: load; individual; equipment; and work-practice-environment. Finally, the-study offered general, as-well-as specific-recommendations, to-improve current-practices of pulling and pushing, at the-department. These should-be useful, to-employers and practitioners, who design and analyze, pushing and pulling-tasks, at the-department, and in-the-textile-printing-industry, at-large.
Keywords: forces, friction, MSDs, MSIs, human-machine-interface.

1. Introduction.

1.1. Pushing and Pulling

1.1.1. Rationale for and definitions.

Regulation 4(1) (b) (ii) of the-Manual-Handling-Operations Regulations (MHOR, 1992), requires the employer to-take appropriate-steps, to-reduce the-risk of injury, from manual-handling-operations, to the-lowest-level, reasonably-practicable. HSE-guidance, in support of this-regulation (HSE, 1998), emphasizes the-importance of 'using the body more efficiently'. One-way, of achieving this is to-substitute lifting-activities with *controlled* pushing or pulling-tasks.

To-reduce the-demands on the-musculoskeletal-system, of operators, during *manual*-materials handling (MMH), industrial-mechanization of these-processes, brought-about carts, dollies, and trolleys, among-others. To-move such-mechanized-aid-equipment, from one-point to the-other, they supposed to be-repeatedly pushed or pulled, by an-operator (Ciriello *et al.,* 2004; Kingma *et al.,* 2003; Laursen& Schibye, 2002; Al-Eisawi *et al.,* 1999a). Consequently, over the-last-decades, the-amount, of pushing and pulling, in-industry, is substantially-increased. Several-researchers pointed-out, that pushing and pulling activities are frequent, for a-great-segment of the-workforce, including hospital-workers, *manufacturing*- workers, construction-workers, and forest-workers, among-others (Vieira & Kumar, 2007; Kee & Seo, 2007; Smith *et al.,* 2006; Hoy *et al.,* 2005). In-particular, Jansen *et al.* (2002); Baril-Gingras & Lortie (1995); and Kumar (1995) report, that pushing and pulling, now account for as-much-as 50% of all MMH-tasks. Besides, Mack *et al.*(1995), indicated, that approximately, 80% of carts are pushed, more-than once, per-day, and 30% are pushed, more-than 10 times, per-day. The-*current*-prevalence of pushing and pulling activities may-be even-higher, than these-statistics suggest.

Baril-Gingras & Lortie (1995) defined pushing and pulling, as-follows:

Pushing and pulling could be defined as the exertion of (hand) force, of which the direction of the major component of the resultant force is horizontal, by someone on another object or person. In pushing the (hand) force is directed away from the body and in pulling the force is directed toward the body.

This-definition, of pushing and pulling, was used for the-present-study. Besides, when setting design-limits, some-authors have chosen to-define pushing and pulling, according-to the-direction of the- force-application. The-three-principal-planes of motion are: (1) Horizontal-pushing and pulling, perpendicular to the-shoulders (horizontal-forces away-from and towards the-body); (2) Horizontal-pushing and pulling, parallel to the-shoulders (transverse or lateral-forces, applied-horizontally); and (3) Vertical- pushing and pulling (see Chaffin *et al.,* 1999).

Often, the-direction of exerted-force is *not* strictly-horizontal, and likely-includes a-vertical component, depending upon the-vertical-height of the-hands, during the-push or pull. In-general, the-vertical component, for pushing, is downward (Boocock *et al.,* 2006). For pulling, when the-hands are below-shoulder-height, the-vertical-component is, likely, upward, and when the-hands are above-shoulder- height, the-vertical-component is, likely, downward. In-some-situations, the-vertical-component, of pushing and pulling-tasks, could-be very-significant, such-as, when an-individual starts a-lawn-mower-engine (Garg *et al.,* 2012). Moreover, some-pushing and pulling-activities may *not* result in-movement of an-object.

On-the-other-hand, Resnick & Chaffin (1995) pointed-out that, although advances in-technology, have-reduced the-number of lifting-tasks, in-industry, these-changes, themselves, cause numerous-*fresh* demands, to-be-placed, on the-human-operator. Pushing, pulling, and maneuvering, hand-carts *still* involve some of the-old-hazards (overexertion), while creating new-ones.

1.1.2. Factors, and Hazards and Risks, associated with pushing and pulling.

Pushing and pulling of mechanical-aid-equipment and objects, exposes workers to two-types of hazards: (1) Overexertion of the-musculoskeletal-system, from exerted-forces, and (2) Accidents, due-to slipping, tripping, falling (Chaffin *et al.*, 1999; Grieve, 1983), or being-hit, by an-object, while pushing or pulling. Rodgers *et al.* (1986) identified three-major-accident-types, related to pushing and pulling, such-as: (1) Fingers and hands, caught-in, on, or between the-trolley, and a-wall, or piece of equipment; (2) Toes, feet, heels, and the-lower-leg, being-bumped, by or caught, and crushed, under the-trolley; and (3) Arm, shoulder, and back-strains, associated with slips, trips, and pushing and pulling of trucks. With powered-trucks, the risks of strain-injuries were-considerably reduced, although hand and foot-injuries will-still be-common.

Numerous-factors, can contribute to-transformation of hazards into risks, and risks into occupational musculoskeletal-disorders (MSDs), musculoskeletal-injuries (MSIs), and accidents, while pushing and/or pulling. These-are the-characteristics of: (1) task; (2) individual; (3) load; (4) environment; (5) equipment; and (6) work-organization and psychosocial-factors. In-particular, the-following-factors are of importance, namely: Friction; Grade/Slope; Wheels; Maintenance of carts and floors; Weight of the-load; Weight of the-cart, itself; Handle-height; Handle-height *vs.* Trunk-posture; Foot-placement; Pushing and pulling- frequency; and Pushing/pulling distance, among-others.

In-terms of work-related factors, exposure can-be-expressed with three-dimensions: intensity (amplitude and direction), frequency, and duration (Neumann *et al*., 2001; Winkel & Mathiassen, 1994). If one of these-dimensions deviates from its-optimum-value, the-risk of musculoskeletal-disorders (MSDs) increases (Hoozemans *et al.,* 2001).

Cross-sectional epidemiological-studies show, that pushing and pulling-activities are associated with low-back and shoulder-pain. Epidemiological-studies show, that 9–18% of the low-back-injuries are associated-with pushing and pulling (Kuijer *et al.,* 2007; Hoozemans *et al.,* 2001; Hildebrandt, 2001; Keyserling, 2000; Ozguler *et al.,* 2000; Meyers *et al.,* 1993; Garg & Moore, 1992; Lee *et al.,* 1992; NIOSH, 1981). However, studies on quantified-physical-exposure, from pushing or pulling-tasks and low-back-pain are lacking. A few-studies have-reported a-relationship, between pushing or pulling and shoulder-pain (Harkness *et al.,* 2003; Hoozemans *et al.,* 2002 a, b; De Looze *et al*., 2000), pushing/pulling heavy-weights (Harkness *et al.,* 2003), and pushing, against a-high-handle (Abel & Frank, 1991). Van der Beek *et al*. (1999) found a-significantly-increased-risk for pain or stiffness in the-neck, shoulder, and upper and lower-extremities. Furthermore, shoulder-complaints are associated with working above acromion-height, twisted-postures, and isometric-load, of the-shoulder-muscles (Van der Beek *et al.,* 2000; Van der Windt *et al.,* 2000), which are frequent-features, in pushing and pulling-tasks. According to Hoozemans *et al.* (1998), conclusive-evidence, relating pushing and pulling, to *other*-musculoskeletal-complaints is still-lacking.

Klein *et al.* found *only* 9% of workers' compensation-claims, for back-strains, related to-pushing and pulling, where overexertion as a-general-category (including lifting, pushing and pulling) accounted for 72% of all-back-strains, and 19% of the-compensation-claims were-spent on back-injuries. Summarizing several-epidemiological-studies (Garg & Moore, 1992; Clemmer *et al.,* 1991; NIOSH, 1981; Snook *et al.,* 1978) Hoozemans *et al.* (1998) reported 9-20% of low-back-claims, to-be-associated-with pushing and pulling. More-recently, WorkSafeAlberta (2010) validated, that up-to 20% of the-injury-claims, for low-back-pain, are the-result of pushing and pulling-activities.

On-the-other-hand, Chaffin has pointed-out, that pushing or pulling is accompanied by an-increased risk for slipping or tripping. A reasonable-part of low-back-injuries is associated-with slipping, or tripping-accidents (De Zwart *et al*., 2001; Deyo *et al*., 2000; De Graaf *et al*., 2000). In-particular, Snook *et al.* found that 7% of low-back-injuries were associated with slipping, tripping, and falling. Ozguler *et al.* (2000) also-showed, that 13% of the-slipping accidents, which resulted in low-back-pain, were associated with pushing and pulling.

The-main-findings, of more-recent-study, by Boocock *et al.* (2006) indicated, that: (1) 11% of MMH related-accidents, investigated by HSE, involved pushing and pulling; (2) The-most frequently-reported-site of injury, was the-back (44%), followed by the-upper-limbs (shoulder, arms, wrist, and hand) accounted for 28.6%; (3) 12% more-accidents involved pulling, than pushing; (4) 61% of accidents, involved pushing and pulling-objects that were *not* supported on-wheels (e.g., bales, desks, rolls, etc.); (5) 35% of pushing and pulling-accidents involved wheeled-objects; (6) The-action of pushing or pulling (e.g. 'the force required to move the trolley resulted in the back injury') was considered to-cause 69% of accidents; (7) Indirect causation of work, was considered, to-occur for 29% of reported-accidents, and typically-involved being-struck by an-object, as a-result of the-pushing or pulling-action.

1.2. Motivation for, and Purpose of, the-study

The-above-statistics and review provide an-idea of how important it-is to-eliminate, or reduce, pushing and pulling risk-factors. Most-reported-studies, presented, are *now*, however, at-least a-decade-old, and with greater-introduction of mechanical-aids, in-the-industry, there is a-real-need to-update such-evidence.

Furthermore, with the-incidence of pushing and pulling, in-industry on the-increase, it could-be logically-expected, that the-percentage of total-musculoskeletal-problems, associated with pushing and pulling, will also-become increasingly-evident.

In-addition, Bernard (1997) stated that scientific-research on Manual-Materials-Handling has-mainly-focused on manual-*lifting* of loads. Recent-studies by Starovoytova (2017 a, 2017b, 2017c, 2017d, and 2017e), done at-the-same-department, have-identified numerous-hazards and risks of Musculoskeletal Disorders (MSDs) and Musculoskeletal Injuries (MSIs), such-as: awkward-postures, repetitive-movements, heavy-lifting, as-well-as mechanical and psychosocial-hazards, among-others.

Besides, handling-materials, by pushing and pulling, have received *only* limited-scientific-attention (Laursen & Schibye, 2002; Jansen *et al.,* 2002; Hoozemans, 2001; NIOSH, 1981), in-spite of estimation that nearly-half of MMH-tasks, consists of pushing and pulling. Ergonomist Duncan Abbott, in his-blog, also-considers pushing and pulling as an-overlooked-aspect of MMH.

On-the-other-hand, Wu (2003) argued that, the-problems, associated with MMH, are more-severe, in-developing-countries, and that further-research, on the-workers of these-countries, is needed. Besides, the-author of this-*unfunded*-study was *not* able to-come-across any-scientific-study, on-pushing and pulling-activities, in a-manufacturing-industry, moreover on textile-industry, in the-local-context. There is, hence, a-need, to-gain greater-insight into pushing and pulling-tasks, performed in manufacturing-industry, as-well-as associated with-them issues. In-the-view of the-above, the-present-study examined hazards and risks, associated with pushing and pulling materials-handling, in textile-printing-operations.

To-give a-broader-perspective, the-following theoretical-coverage was-also provided, in the-next sections, such-as: 'Pushing *vs.* pulling' ongoing-debate; Pushing and Pulling Capability-Standards, Guidelines, and tools; Pushing and pulling-task phases and forces, involved; as-well-as relevant factors and characteristics of: load; individual; equipment; and work-practice and environment. Finally, the-study offered general, as-well-as specific-recommendations, on how to-improve current-practices of pulling and pushing, at the-department.

2. Materials and Methods.

2.1. Description of the-textile-mill, where the-study was conducted.

The-current-study was conducted at Rivatex-East-Africa, Limited (REAL), an-integrated textile-mill, which is fully-equipped to-handle the-entire textile-processing-cycle. Raw-materials utilized, by the-factory, are: cotton, polyester, and viscose. For more-details, on the-mill's history, structure, and end-products (see Starovoytova, 2017a). The-focus of the-current-study was on printing-section, of the-finishing-department, at the-mill.

2.2. Main-instruments used

The-following-instruments were used: document-analysis, a-questionnaire, and observations. Check-list, on pushing and pulling risk-assessment, by HSE (2004), was-used, as a-point of reference, in designing a-questionnaire, for this-study. Observations were done *via* a-series of site-visits, during 3months-period. Combination of observational-methods and questionnaires, in-risks and hazards-assessment, has-been also-recommended, in the-literature (see Descatha *et al.,* 2009; Barrero *et al.,* 2009; Barriera-Viruet *et al.,* 2006; Spielholz *et al.,* 2001).

2.3. Focus and design of the-study.
In-order to-conduct a-survey and perform a-document-analysis, the-study was divided-into 3-distinctive parts, which shown in-Figure1.

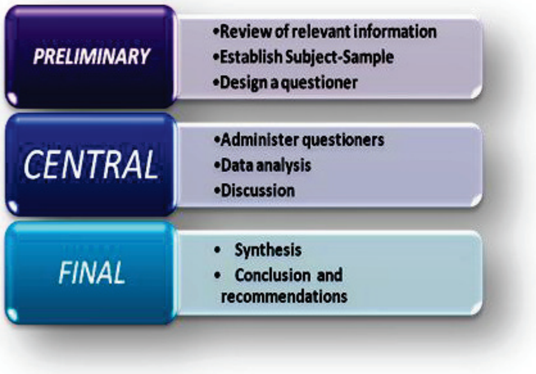


Figure1: Sequential-parts of the-study (Starovoytova & Namango, 2016).

2.4. Sample size and the-rationale for its-selection
To-evaluate pushing and pulling-hazards, among printing-machine-operators, at the-REAL, a-confidential self-report-questioner was designed and used, as the-main-instrument, for this-study, with the-sample-size of 12-subjects (representing the-entire machine-operating-staff, at the-finishing-department).

2.5. Data Analysis
This-research complies with the-ISO 20252:2006 (E): Market, Opinion and Social-Research Standard; hence, a-preliminary-study was-conducted, at the-factory, using an-initial-version-questionnaire, for determining the-hazards.

To-estimate reliability, the-correlation-coefficient was used, according to Kothari (2004). The Statistical Package for Social-Sciences (SPPS-17, version 22)-computer software-program was applied, to-compute the-Cronbach's co-efficient. Descriptive-statistics was employed to-analyze both; qualitative and quantitative-data.

2.6. Terminology applied
Definitions and important-differences, between 'hazard' and 'risk' (in the-context of OSH), pointed-out, by Starovoytova (2017 b), were applied, in-this-study.

3. Results.
3.1. Validation of the-Questionnaire
Initially, the-check-list was modified, to-suit the-specifics of the-study. Upon-validation, the-general recommendation made, is that the-instrument was-acceptable, with some-minor-editing. Questionnaire-data was-coded, entered into-SPSS, and checked for-errors. Data was analyzed, list-wise, in-SPSS, so that the-missing-values were-ignored. Cronbach's-alpha-test of internal-consistency was-performed, for perceptions and self-reports, and established relatively-high inter-item-consistency (Cronbach's $a > 0.78$).

3.2. Analysis of the-questionnaire.
Analogous to previous-study by Starovoytova (2017 b), 12 questionnaires were-administered to-the-entire staff (machine-operators) of the-finishing-department, printing-section; the-response-rate (RR), for this-study, was 92% (11 duly-completed questionnaires).
3.2.1. Analysis of part1: Demographic-Characteristics.
Table 1 shows the-demographic-characteristics of the-respondents.

Table1: Demographic-information of the-respondents (Starovoytova, 2017 b).

	Mean	S D	Range
Age (yrs)	25.375	10.23	24 - 43
Duration of Employment (yrs)	2. 75	2.18	1 - 8
Height (cm)	169.07	11.84	146 - 182
Weight (kg)	65.375	9.80	54 - 85

3. 2.2. Responses to the-questionnaire
To-avoid replication, responses and their-analysis, were-provided, concurrently, in-this-section, as-follows:

Majority (91%) of the-respondents indicated, that:

(1) *Repetitive*-pushing and pulling-tasks, were-conducted, daily;

Repetition, or frequency, is typically-related to the-task-cycle. For-example, if a-task-cycle includes pushing equipment seven-times, every-hour, then, the-repetition/frequency-rate is 7/hour, or 0.12/minute, or 0,002/second. Increasing the-frequency of pushing or pulling, induces muscular-fatigue, and reduces the-amount of force, that can-be-generated, along with the-number of people, who are capable of performing such-tasks (Lee, 2007; Snook & Ciriello, 1991). Besides, several-studies have-reported, that both; initial and sustained-maximum-acceptable pushing and pulling-forces decrease, with an-increase in frequency of exertion (Snook& Ciriello, 1991; Snook, 1978). Repetitive-pushing and pulling, increases the-frequency of application, of exerted-forces, and hence increases operator's metabolic-demand, and also-reduces the-amount of time, body-tissues-have, to-recover, between-loading. Besides, as repetition increases, the-force a-person can-exert, decreases, especially as the-length of time (duration) of the-task-increases, and, hence, repetitive-pushing and pulling should-be avoided, as-much-as practicable.

On-the-other-hand, the-*duration* of a-task is the-length of time, it-is performed. For-example, if a-worker pushes equipment for 2 hours, a-day, the-duration, of that-pushing-task is 2 hours. In this-case, duration is *not* the-duration of a-single-exertion, but the-duration of the-push or pull-task, in a-given working-day.

When a-manual-material-handling-job requires highly-repetitive, fast-paced, or forceful-exertions, Physical Work Capacity (PWC), and fatigue, must-be considered. PWC is a-measurement of maximum- aerobic-capacity, or metabolic-expenditure-capabilities. PWC is affected by: age (decreases with age), fitness, gender (men typically have a-higher PWC, than women), maximum heart-rate, and the-energy demands of the-job (repetition, exertion-levels, and duration, or length of time, spent performing the-job). When physiological-limits are exceeded, fatigue occurs, and in severe-cases, a person's cardiovascular- system may-be-stressed, to-the-point of heart-failure (Lee, 2007).

(2) The-loads were heavy; moreover operators were *not* aware about the-actual-weigh of a-particular load, they to-transport, so they just-approximated.

Datta, with his-colleagues, found that the-linear-relation, between an-increase in cart/trolley-weight, and an-increase in energy-expenditure (*E*), pulmonary-ventilation (V_E), and heart-rate (*HR*). Moreover, if a-lifter does *not* know the-weight of a-load, they can*not* prepare-themselves, well, for a-required-force, to-be-exerted. It-is, therefore, beneficial to-look at the-standards and guidelines, relevant-to pushing and pulling-tasks.

(a) Pushing and Pulling Capability Standards

(i) BS EN 1005-3:2002, Safety of machinery—Human-physical-performance, Part 3: Recommended-force-limits for machinery-operation, is standard, which specifies recommended-force-limits, for-actions, during the-construction, transport, commissioning, use, decommissioning, disposal, and dismantling of machinery. It-is-applicable to-machinery, for professional-use, by healthy-adult-workers, with normal-capability, as-well-as to-machinery, for domestic-use, that may-be operated by the-whole-population, including youths, and older-people. The-approach involves 3 steps: (1) The-maximal isometric-force-generating-capacity is determined, for the-relevant-actions, within the-intended-user-population (see Table 1).

Table 1: Maximal-isometric-forces, by the-general European-working-population, for whole-body-work in a-standing-posture (BS EN 1005-3:2002).

Activity	Professional Use	Domestic Use
Pushing	200 N (20.4 kg)	119 N (12.1 kg)
Pulling	145 N (14.8 kg)	96 N (9.8 kg)

(2) The-maximal force-generating-capacity is reduced, according to-the-circumstances, under which the-force is to-be-generated (velocity, frequency, and duration of action). The-extent, of force-reduction, is specified with a-set of multipliers. If the-action implies an-evident-motion, the-velocity-multiplier is reduced from 1.0 to 0.8. The-duration-multiplier is 1.0, for durations less-than 1 hour, 0.8 for durations of 1-2 hours, and 0.5, for durations of 2-8 hours. The-frequency-multiplier, depends on-both; the-action-time (duration, of each-action), and the-frequency, at which the-action-occurs; and (3) The-reduced-force- capability, representing the-very-limit of force-exertion, possible, is evaluated with risk-multipliers, to-determine the-risk-zone, associated-with action-forces, during machinery use.

(ii) Another-relevant-standard is ISO 11228-2: 2003--Manual handling and force limits – Part 2: Pushing and pulling, builds upon BS EN 1005-3:2002, by providing two-methods of pushing and pulling-risk-assessment. In-Method 1, a-pushing and pulling general-assessment-checklist is completed. The-results of the-checklist are considered, in conjunction-with, appropriate-psychophysical-data (Snook & Ciriello, 1991) to-determine an-overall-risk of injury.

Method 2, as with BS EN 1005-2:2002, determines force-limits, according to-basic muscular-strength-limits, adjusted, according-to-the intended-population, and task-characteristics (distance, and frequency, of the-push or pull-task). Finally, an-approach, for measuring pushing and pulling-forces, is suggested.

(iii) Work-Environment-Standards.

Hazards of the-working-environment are identified in both; pushing and pulling force-limitation-standards. BS EN 1005-3:2003 refers to extreme-temperatures, humidity, and lighting-conditions. ISO/WD 11228-2:2203 makes additional-reference to the-maintenance of surfaces, over which an-object is pushed or pulled, as-well-as slopes, ramps, and steps, which-increase the-physical-effort, of the-task.

(b) Guidelines and tools

Snook, Ciriello and their-colleagues, at the-Liberty-Mutual-Research-Institute, have-conducted most of the-studies on maximum-acceptable pushing and pulling-forces, reported in the-literature (see Boocock *et al.,* 2006; Ciriello *et al.,*1999, 1991; Ciriello & Snook, 1983; Snook, 1978). Using a-psychophysical- methodology, Snook, Ciriello and their-colleagues determined maximum-acceptable initial and sustained-pushing and pulling-forces, across a-wide range of task-conditions.

More-recently, Garg *et al.* (2012) presented multiple-regression equations, for determination of push-forces, for both-genders, as-follows:

Initial Push Force Acceptable to 75% of Male Workers:

$$F=11.617-1.938*\ln(E)-0.0678*\ln(E)^2-4.457*\ln(D)+0.484*H-0.00228*H^2$$

Sustained Push Force Acceptable to 75% of Male Workers:

$$F=19.816-2.059*\ln(E)*D^{-0.135}-3.241*\ln(D)+0.0514*H-0.000225*H^2$$

Initial Pull Force Acceptable to 75% of Male Workers:

$$F=40.056-1.856*\ln(E)-0.0629*\ln(E)^2-0.216*D-0.132*H$$

Sustained Pull Force Acceptable to 75% of Male Workers:

$$F=21.741-1.932*\ln(E)*D^{-0.130}-2.928*\ln(D)+0.0569*H-0.000572*H^2$$

Where: F = Initial or sustained maximum acceptable pushing or pulling force (kg);
D = Pushing or pulling distance (m);
E = Pushing or pulling frequency (Exertions/min); and
H = Handle height (cm)

Correlation-coefficients and standard-errors, for the-above regression-equations are provided in Table 1 of Garg *et al.* (2012). These-equations are valid, for frequency of exertion, ranging from one-push or pull, every 8 hours, to one-push or pull, every 6 seconds, pushing or pulling-distances, ranging from 2.1m to 61m, and handle-height, ranging from 57cm to 135cm, for-females, and 64-144cm, for-males. When designing new-pushing or pulling-tasks, it-is strongly-recommended, that users of these-equations refer to Snook & Ciriello (1991) tables, for guidance, in-determining feasible-combinations of frequency and distance. These-tables are a-useful-reference-tool, which takes various-conditions, into-account, when recommending a-push or pull-force-limit; they can-be-found in the-Snook-tables, published by the-Liberty-Mutual Research-Institute for Safety.

In-addition, few-studies have-assessed oxygen-uptake (VO2) and/or heart-rate (HR) for psycho- physically-determined maximum acceptable-pushing and pulling-forces (Dempsey *et al.,* 2008; Ciriello *et al.,* 1993; Snook & Ciriello, 1991).

On-the-other-hand, in-North-America, limiting the-risk of injury, while handling carts, is commonly- done by-keeping the-operating-forces, at or below, a-reference-force-limit. For-example, starting a-cart- moving should *not* require a-force more-than 220N. However, that recommended-force changes, depending on various-conditions, such-as: the-gender of the-person, doing the-work; the-distance, that they move the-load; whether it-is the-force, necessary to-start the-cart-moving, or just to-keep-it in-motion; and how-often the-loaded cart is moved, etc.

Besides, Resnick & Chaffin (1995) assert, that due to-biomechanical-criteria the-load, moved in a-four-wheeled-container should *not* exceed 225kg. They further-recommend, that loads should *not* exceed 114 kg, for two-wheeled-carts. Moreover, general-recommendations, were given: (1) the-load, on hand- pallet-carts can be up-to approximately 700kg; (2) manual-carts should *not* be used more-than 200-times, a-work-day; and (3) the-load should *not* be-transported more-than 30-35 meters, per 'shipment'.

Regardless of the 'other' factors, involved, Van der Beek *et al.* (2000) and Eastman-Kodak Co. (1986), argued, that the-loads-moved, should-be-kept as-low-as-possible.

These-values, however, do *not* consider the actual-magnitude of the-pushing or pulling-forces, required, and, hence, should-be-used with caution.

Moreover, the-British Health and Safety Executive's Risk-Assessment of Pushing and Pulling (RAPP) tool calls-out the-importance of maintaining carts, in-order-to-maintain the-operating-forces, at, or below, the-recommended-limits.

Lastly, to-calculate the-maximum safe-load, that can-be-moved, the-percentage of men or women, who could-handle the-task, without excessive-risk of musculoskeletal-problems, Canadian government-funded workers' safety-site provided useful-online-calculator, which allows users to-input factors, such-as the- distance, any-load will-be-pushed, pulled, or carried, and the-height of the-load, while performing the-task. See more-details *via* http://ergonomics.healthandsafetycentre.org/calculator/ergo/default.htm. In-addition, the-Health and Safety-Executive's 2004 research-report, on pushing and pulling, is available *via* www.hse.gov.uk/

(3) The-respondents also-pointed-out, that high-initial-forces were-required, to-get the-load moving;

Newtons (N) are commonly-used, to-measure forces, in *any*-direction, as opposed-to kilograms, which measure how-much-effort is needed, to-lift something-upwards (as a-guide it-takes about 10N to-lift one kilogram). The-force, needed to-move a-load, could-be-measured using a-spring-balance, by attaching the-balance to the-loads-handle, pulling the-load, and noting-down the-figures. Specialized-tools, such-as dynamometers, can also-measure the-force, needed to-move a-load.

Higher-force-requirements increase fatigue, and contribute to-overexertion-accidents, such-as muscle-strains of the-shoulders, arms, and back (Hoozemans *et al.,* 1998). High-forces are also-limit the-number of people, capable of performing, the-task (Snook & Ciriello, 1991; Rodgers *et al.,* 1986). To-prevent, or limit, overexertion, and other-related-accidents, it-is beneficial to-understand the-stages of pushing and pulling, as-well-as the-forces, involved.

According to Lee *et al.* (1991) pushing and pulling can-be-separated into two-activities, one, where the-object is *not* moved (static), and the-other-activity, which results in the-movement of the-object (dynamic). During dynamic-tasks, the-push or pull-force can-be-further subdivided-into: (1) the-initial force, required to-accelerate the-object; (2) the-sustained-force, to-keep the-object moving; (3) turning- force; and (4) the-force, required to-bring the-object to a-stop. The-dynamic-forces exist *only* when the- equipment is being-accelerated (or decelerated). Acceleration occurs at-the-start, of a-push, as the-load is accelerated, from a stationary-position to some-movement-velocity; when the-load is slowed, causing a-change, in-velocity; and when the-equipment is turned, causing an-acceleration in a-new-direction.

To-start the-motion, the-operator *must* overcome inertial-forces, friction-forces, and any-other- mechanical or physical-forces, that may-be due-to such-factors-as: flat-spots, on the-wheel; and/or debris or irregularities, on the-floor. The-forces, that resist movement, generally-referred-to-as *Rolling Resistance*, define how-much-force a-person *must* generate, and apply. Several-types of forces combine to resist-movement: (1) Dynamic, or Inertial-forces; (2) Forces, due to-physical-interference; and (3) Friction- forces. Figure 2 shows forces, at the-caster and wheel, which resist movement; including friction in-the-axle, friction at the-swivel-axle, and friction and physical-interference, at the-floor-ground-interface.

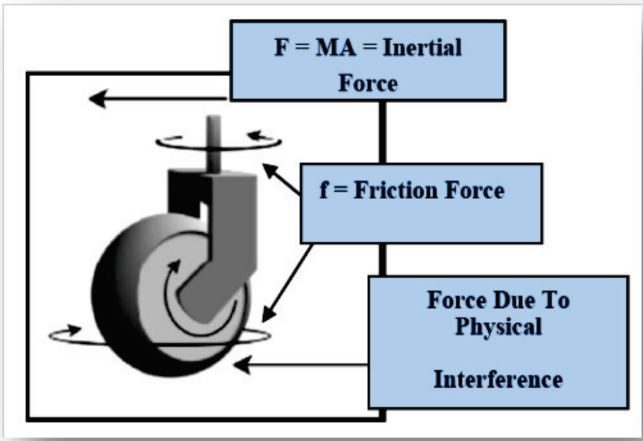


Figure 2: Rolling-Resistance (Adopted from Darcor & Ergoweb, 2001).

The-initial push-force is always-higher, than-the-sustained-force, in-part, because it-includes the-force, required-to overcome-inertia. Push-force is directly-related to the-acceleration, with-which the-force is applied. Isaac Newton determined the-relationship, among force, acceleration, and the-mass (which is directly-related to the-weight) of an-object to-be: *Force = Mass X Acceleration; (F = Ma).*

When an-operator push wheeled-equipment, they generate force, and transmit that-force, through a-contact-point, with the-equipment (such-as handle). Friction, at their-feet, *must* be, at-least-equal to the-resisting-forces, of the-equipment, otherwise their-feet will-slip.

If a-wheel is turned, additional-resistance must-be-overcome, until it aligns in the-direction of travel. Under-typical-conditions, the-force (the-level of muscular-effort) to-initiate-movement, is always-higher, than the-force, required to-sustain-movement. Fortunately, the-initial-forces typically last a-short-time, and drop to the-sustained-force-levels, once the-acceleration, and any-mechanical-interference, at the-start of movement, is overcome.

Once-started, the-operator, usually, does *not* need to-apply-much, if-any, acceleration (e.g., any-change in-velocity; can-be-an-increase, or decrease, of-speed). Therefore, the inertial-forces are either; go-to-zero, or become-low, once moving, at a-relatively-constant-velocity; the-forces, resisting movement, are-restricted to-friction, and physical-interference, from wheels, or floor-irregularities, and momentum tend to-keep the-equipment, in-motion.

On-the-other-hand, two-primary-forces combine, when the-cart is turned: (1) inertia, due to-acceleration, in a-new-direction; and (2) friction in the-swivel-housing, and between the-floor and the-wheel. The cart's momentum, which is related to its-mass (weight), wants to-carry the-cart, in the-direction, it-was-traveling, so the-operator *must* overcome that, by applying higher-forces, in the-new- direction. A-well-designed and maintained-caster will have low-frictional-resistance, to-turning, at the-bearings, in the-caster-housing, so the-real-friction-concern is related to any-pivoting, at the-wheel ground-interface. Depending on the-weight of the-cart, the-acceleration, at which it-is turned, and the-friction, at the-casters, the-turning-forces can-be-significant. The-result is that, an-operator will-need to-apply new-forces, in new-directions, often in-asymmetric-body-postures and muscle-exertions, which can-increase the-likelihood of MSDs and MSIs.

If, at-the-end, of the-travel-route, the-operator can simply-release, the-cart and let-it-roll, to a-stop, on its-own, there is *no* need, to-apply any-force. However, if it *must* be stopped, or positioned, in a-specific place, the-forces can-be significant, and multidirectional, in the-case of positioning. Such-multidirectional- forces can expose the-operator, to-potentially hazardous-postures, and muscle-exertions. Stopping, in-terms of inertial-forces, is the-same as-starting, but additional-force is applied, to-decelerate, rather than accelerate. Positioning, on-the-other-hand, is a-series of starting, stopping, and turning-forces, which are typically the-highest-force-conditions, required in a-pushing-task.

(4) The-respondents claimed that loads lacked good-handholds;

If the-load is difficult to-grasp, its-handling will-demand extra-grip-strength, which is tiring, and may involve an increased-risk of dropping the-load (HSE, 1998). Besides, if there are *no* suitable-handles, protruding from the-object, fingers are more-likely to-become-trapped (Roebuck & Norton, 2002). The handler's ankles are also-more-likely to-be-hit by a-trolley, without protruding-handles (Lawson *et al.,* 1993).

(5) Pushing and pulling-tasks were-conducted, in-confined-spaces and/or narrow-doorways;

According to Boocock (2003), 11% of all push-pull-accidents, reported, were deemed to-be-caused by a-collision, or trapping. Confined-spaces increase the-risk of collisions, with people, or objects, and the-additional-maneuvering-required, results in more-frequent-twisting, and force-exertion, by the-handler. On-the-other-hand, pushing and pulling a-trolley, while holding a-door-open, results in twisted-postures, and one-handed-pushing and pulling. Trolleys, must-be-able to-fit conveniently, through-doorways, to-provide safety to-handlers' limbs, and to-reduce damage to door-jambs (Lawson *et al.,* 1993).

73% stated that they performed more pushing, than pulling.

From the-operational-point of view, pushing, is preferable-to-pulling, for several-reasons, such-as: (1) pushing, presumably, involves less-work, by the-muscles of the-lower-back; (2) it generally allows better-vision, of the-direction of movement; (3) There is no 'run-over', by the-equipment, when pushing; and (4) If one pulls a-load, while facing the-direction of travel, their-arm is stretched, behind their-body, placing shoulder and back, in an-awkward-position, that increases the-likelihood of MSIs; and (5) Most-people can-develop higher-push-forces, by leaning their-body-weight, into the-load.

The-choice of pushing or pulling may-also-depend on the-size and shape, of the-handle-design, or the-amount of force, required. Power-grip (also known as cylindrical-grip) uses the-whole-hand, and is the-best-choice, when great-pull-push-forces are needed. But individuals may not be-able to-achieve this-force, if the-handle is not big-enough, or it-is incorrectly-shaped, to-accommodate a-power-grip.

On-the-other-hand, Ciriello et al. (1999) analyzed 25, 291 MMH-tasks, including 1879 pushing-tasks and 1866 pulling-tasks. According to their-survey, 60% of pushing-tasks, required an-initial-force, greater than 155 N and 28% >311 N. Approximately 46% of pushing-tasks required a sustained-force >111 N and 12% >244 N.

Pushing-distance ranged from <1.5m to >30.5m, with 24% of tasks, requiring a-pushing-distance, between 1.5 and 6.1m, and 70% of tasks had pushing-distance ≤18 m. About 93% of pushing-tasks were-performed once, per-minute, or less often, and 68% were performed once, per 5 min, or less. Handle-heights ranged from <12 cm to >203 cm, with 6% of pushes occurring, below knuckle-height (76 cm). A-large-majority (60%) of pushes was performed, between 76 cm (about knuckle-height) and 114 cm (about elbow-height). Overall, pulling-data, from Ciriello et al. (1999) showed that pulling characteristics were comparable-to pushing-characteristics.

Besides, Van der Beek et al. (2000) investigated pushing vs. pushing, and found that oxygen- consumption and heart-rate were higher, in pulling, than pushing, for both; males and females, and at all-body-masses, tested.

Psychophysical-studies, on maximum-acceptable-forces, for pushing and pulling of carts, have found: either no statistically-significant-differences, between pushing and pulling-maximum-acceptable-forces, or reported, that pushing resulted in higher-maximum-acceptable-forces (Boocock et al., 2006; Ciriello et al., 1993; Snook & Ciriello, 1991). For-example, Ciriello et al. (1993) reported, that the-initial and the-sustained maximum-acceptable-forces, for pulling-tasks were 13% and 20% lower, than those for pushing-tasks, though not statistically-significant. Similarly, Boocock et al. (2006) reported, that the-maximum acceptable-pushing-forces were-slightly-higher, than those for pulling. In-addition, Al-Eisawi et al. (1999a) stated that, on-average, pushing required 93.5% of pulling-forces, for pushing the-same cart-weights. Pushing, also results in lower-compressive-force, than pulling (Hoozemans et al., 2004; Lee et al., 1991). Others have-reported, that, pulling-tasks, as-compared to-pushing-tasks, result in lower-compressive and shear-forces (Lett & McGill, 2006). In a-biomechanical-study, comparing spinal-loading, for a-simple pushing and pulling-task, Knapik & Marras (2009) found, that the-nature of exertion, played a-major-role in defining spine-forces, with pushing, resulting-in significantly-greater anterior/posterior (A/P) shear-forces, compared with a-comparable pulling-task, at all-levels, of the-spine, except for L5/S1.

The-results are also-inconsistent, when comparing maximum-pushing-strength with maximum-pulling strength. Daams (1993) and Keyserling et al. (1980) found no significant-differences, between pushing and pulling-maximum isometric-strengths. But, Kumar et al. (1995) found pulling-isometric-strengths, to-be greater than pushing-isometric-strengths. On-the-other-hand, Van der Beek et al. (2000) and Chaffin et al. (1983) reported that pushing-strengths were higher, than pulling-strengths. These-inconsistencies, between pushing and pulling-strengths, might be-due-to the-following-differences: in-study-populations used; study- design, including instructions-to-subjects; or instrumentation, used to-measure forces, and/or differences in body-postures, and techniques, used (for-example, pushing or pulling, horizontally vs. at-an-angle).

At-present, it-is not clearly-established, whether; pushing or pulling, results in lower-stresses, to the-workers. It appears, that workers used more pushing, that pulling, because they perceive it easier and safer. On-the-other-hand, Straker et al. (1996), stated, that the-physical-limits, for both; pushing and pulling, being-subjectively-rated, as less-strenuous, than MMH, particularly lifting. They found that, the-limits, for pushing and pulling, more-than double, the-limits for lifting, lowering, and carrying.

64% stated, that pushing and pulling involved:

(1) Manoeuvring of the-load, into-position, or around-obstacles;

Manoeuvring-operations, often-take-place, in restricted-spaces, where the-object, being-handled has to-be-turned, or placed into a-particular-location, with a-certain-degree of precision. In-such-instances, the-forces, which a-person can-exert are often-considerably-less, than in-unrestricted-situations, as the-operator is unable, to-position their-body-weight, behind the-centre of gravity, of the-load (Rodgers et al., 1986).

(2) Some of the-MH-equipment was without brakes, making it difficult to-stop;

Brakes, can-reduce the-amount of restraining-force, required by the-operator, to-slow-down, or stop, the-trolley, and control the-trolley, down a-slope (Rodgers et al., 1986). Brakes also should-be-applied to-trolleys, when they are loaded and unloaded (Roebuck & Norton, 2002; Lawson et al, 1993) as a-sudden movement can-impose unpredictable-stresses, on the-body, and increase the-risk of injury (HSE, 1998). Brakes are important, for-the-safety of the-operator, as-well-as for preservation of the-materials, they curry, hence, they should-be-installed, where missing, at the-department.

(3) Floors were largely-uneven, damaged, and/or slippery.

In-addition-to-increasing the-likelihood of slips, trips, and falls, uneven or slippery-floors impede smooth-movement, and create additional-unpredictability (HSE, 1998). Ridges, gaps, or holes, can increase the-force, required to-move-trolleys, by large-amounts, and result in strain-injuries (Roebuck & Norton, 2002; NOHSC, 1999). A-slippery-floor will also-reduce pushing and pulling-capability (Konz& Johnson, 2004; Chaffin et al., 1999).

45% claimed, that:

(1) Occasionally, push or pull-movements involved high-speed and/or long-distances;

Logically, it-is more-difficult to-control-loads, moving at-speeds faster, than a-walking-pace (Rodgers et al., 1986), and the-risk of injury is, hence, increase with increase-in-speed (Lee et al., 1991). The-movement of loads, at-high-speeds may-involve high-accelerations, to-start, to-maintain, and to-stop the-motion, as-well-as change the-direction of the-moving-load (Rodgers et al., 1986). These-high-accelerations imply large-tissue-forces and an-increased risk of injury.

On-the-other-hand, further-distances require longer-periods of force-application. If physical-stresses are prolonged, then fatigue will-rapidly-occur (HSE, 1998). This will-reduce the-amount of force, that can-be-sustained, along-with the-number of people, who are capable of performing the-task (Snook & Ciriello, 1991; Rodgers et al., 1986). Besides, several-studies, using a-psychophysical-approach, have- shown, that both; the-initial and sustained-forces, decrease with an-increase in pushing or pulling-distance (see Snook & Ciriello, 1991; Snook, 1978). It-is, therefore, only logical, to-recommend to-design pushing and pulling-tasks, with moderate speed and distance, as-much-as-practicable.

(2) MH-equipment (trolleys, carts), and floor-surfaces, were poorly-maintained, cleaned, and/or repaired;
Mechanical-aid-equipment does wear-out; the-frames get-bent, and do not track quite-true; wheels get-cut, or go-out of round; bearings are also-wear-out, after some-time of continual and extensive-operations. All-these change the-forces, required to-operate the-MH-equipment; what was once low-risk may no longer be-safe. According to Lawson and his-colleagues, poorly-maintained-trolleys and cats, get progressively more-difficult to-operate; broken-trolleys become, even, dangerous.

On-the-other-hand, floor-surfaces, that are not maintained, will-become heavily-etched, cracked, and covered, with in-process-materials, making MH difficult, and increasing the-risk of a-slip, trip, and/or fall (Rodgers et al., 1986). Maintenance, of the-wheels and wheel-bearings, affect the-amount of pushing or pulling-force, required to-move a-cart. In-addition, Das et al. (2002) reported, that a-cart, equipped-with ball-bearing-casters was-easier to-push or pull, than carts, equipped-with sleeve-bearing-casters; this should-be considered, when choosing the-design for new-purchases of MH-equipment, at the-department.

Uneven-floor-surfaces can significantly-increase the-force, required to-push or pull, a-cart. Lawson et al. (1993) reported, that ridges, between uneven-floors, ranged between 1 and 2cm in-height, and in some-cases up-to 5cm. Pushing and pulling of carts, over these-ridges required more-than 490N of force (Lawson et al., 1993). Similarly, moments on the-lower-back, close-to 400N, have-been-reported, when pulling a-four-wheeled-container, over a-curb (de Looze et al., 1995; Frings-Dresen et al., 1995a; 1995 b). Besides, Boocock et al. (2006) concluded, that risk of injury, to the-handler, is most-likely to-occur, when there is a-sudden-change, in the-frictional-properties, of the-floor-surface, such-as: contamination with fluid, that creates a-marked-difference, between actual and expected-floor-properties.

Floor-maintenance and good-housekeeping can have a-dramatic-effect on the-forces, experienced by the-operator, the-stability of the-load, and the-physical-life of the-equipment, among-others. MH equipment (trolleys, carts), and floor-surfaces, therefore, should-be regularly-maintained, at the-department (see more-details on maintenance in recent-study, published by Starovoytova (2017 c)).

(3) The-majority of MH-equipment was heavy, old, and hard to-steer;
For a-given-cart, and floor-surface, as the-weight of the-cart increases, the-force, required to-push, or pull, that-cart, increases-linearly (Al-Eisawi et al., 1999a). The-relationship, between the-weight of the-cart, and the-amount of force, required to-push or pull, the-cart, is affected by a-number of factors, including: wheel-diameter and width, wheel-composition/materials (e.g. hard vs. soft), type of axle-bearing, flooring- surface, handle-type, and height (affecting magnitude of vertical-component of force), cart-acceleration, and velocity.

A-cart, that is not-properly-balanced, however, requires more-force, to-push or pull, and makes-it difficult to-maintain the-direction of movement. The-same is true, when the-wheels are not properly-aligned.

To-steer, effectively, the-number, arrangement, diameter, and composition, of the-wheels, must-all-be suited, to the-surface-characteristics, and the-nature of the-steering-task (Lawson et al., 1993). Wheels, that are difficult to-steer, will increase the-force, required by the-operator to-manoeuvre the-trolley, leading to fatigue.

(4) There was an-absence of the-suitable PPE, provided, and, hence, worn, by the-operators;
Suitable-PPE should-consider, among many-things, the-risks of the-workplace, and the-parts of the-body. PPE is more-likely to-be-worn, if the-demands of the-job are considered, such, as the-physical-effort, required to-do the-job, the-methods of work, the-duration of PPE-usage, visibility-requirements, and communication-requirements. Differences in the-physical-dimensions of workers may-require more-than one-type or size of PPE. There-may-be-an-absence of suitable PPE, if an-effective-system of their- maintenance and replacement, is not established (HSE, 1992).

Lastly, it-is-worth to-mention, that the-rest of the-respondents (for each-question) did largely-opposed the-above-answers.

In-addition to the-questionnaire, observation of different-pushing and pulling-practices, was conducted; one-illustrative-example of which, is presented in the-next-section.

4. Discussion.

As-stated by the-respondents, they had-been-experiencing difficulties, in-pushing and pulling of the-MH-equipment, and in-particular: they had-to-assume awkward-postures, and they had-to-exert, significant-force, to-start the-movement, and to-maneuver trolleys, during pushing or pulling. There are numerous-reasons that could-be behind such-complains. To-offer informed and tailored-recommendations, on how to-improve the-current push and pull-practices, it-would-be beneficial, first, to-examine the- *observed* practices, at-the-department, supplemented by selected-theoretical-aspects, relevant-to pushing and pulling-tasks; these were the-focus of this-discussion.

4.1. Pushing-practices reported and observed.

To-understand the-reasons, behind such-difficulties, observations were conducted, of pushing and pulling practices, at the-department. The-following-example will-be limited to *pushing*-task, as the-most-common practice, at the-department.

Figure 3, shows diagrammatical-representation of one of the-observed-practices. In-the-author's opinion, this-particular-practice, captures the-very-essence of a-pushing-task, where a-machine-operator, *must*-overcome the-forces, that-resist-motion, therefore he is pushing, hard. To-generate and apply force, to-the-trolley, the-operator *must*-have adequate-friction, or traction, at his-feet; he must-be able to-generate adequate-strength; and he must-apply his-force, to the-equipment, through the-hands. Actually, human machine-interface, in-this-particular-case, is hands, holding the-handle of the-trolley. Ergonomists refer to the-hand-equipment-interface as 'coupling', and research shows, that poor-coupling can-lead to as-much-as a 65% decrease in push-pull force-capabilities (Lee *et al.,* 2007).

Significant-force must-be-applied, by the-operator, to-start the-movement; he, hence, assumed a-posture, that maximizes his-ability to-generate high-forces, using his large-muscle-groups (in the-legs and torso), by aligning his-body, with the-horizontal-force (see Figure 3). This-operator has added-benefit, of using part of his-own body-weight, to-generate the-force, and extending his-feet, behind his-center of gravity, requiring high foot-floor-friction-forces. The-observed-awkward-posture, assumed by the-operator, is in-accord-with the-statement of Todd & James (2004) that, pushing often requiring workers to-adopt awkward-working-postures, in order to-achieve the-required force-output.

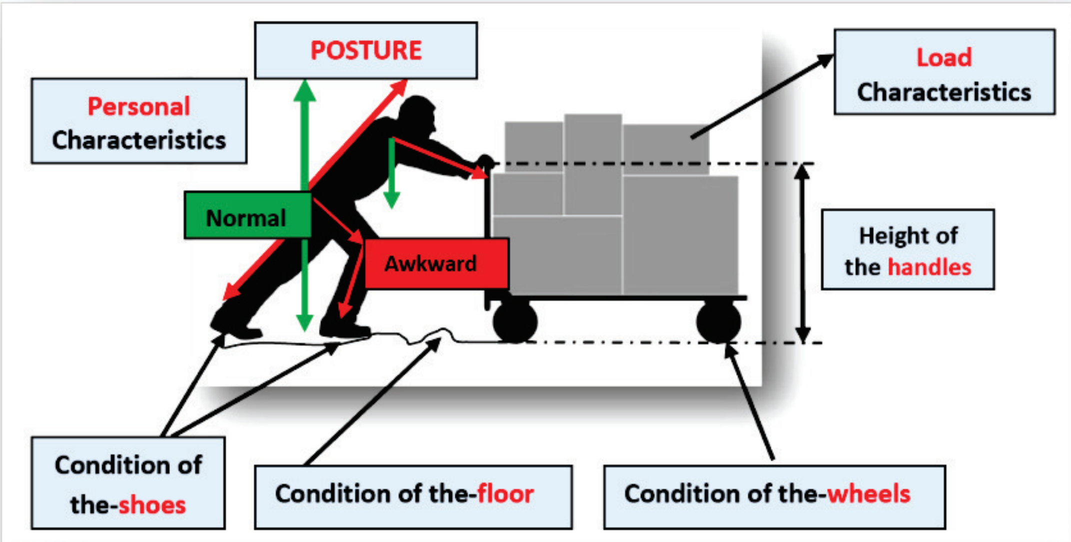


Figure 3: Major-factors, affecting pushing of load.

The-force, required to-move a-cart is in-the-plane horizontal-to-movement. That is, for a-cart, being-pushed on a-flat-surface, the-most-effective force-application will-be in the-direction, parallel to-the floor. In-an-actual pushing-situation, however, the-person may-be unable to-apply the-force, *exactly*, in the-horizontal-direction. For-example, Rodgers *et al.* (1986) list the-following-variables, as being important-factors, governing the-ability to-exert horizontal-push-pull-forces: (1) Bodyweight; (2) Height of force-application; (3) Distance of force-application, from the-body, or the-amount of trunk-flexion, or extension; (4) Frictional-coefficient of the-floor; (5) Frictional-coefficient, of the-shoes; (6) Duration of force-application, or the-distance moved; and (7) Availability of a-structure, against-which the-feet or back, can-push, or prevent-slippage.

Awkward-posture (trunk-bended-forward), affects forces, in trunk-muscles (back and abdominal), and compressive and shear-forces, on spinal-discs, and stresses to-shoulder-joints, and can-lead-to MSDs and/or MSIs. MSIs are more-likely to-occur to the-back (muscles, tendons, ligaments, and discs), when the-back is fully-bent-forward, because the-muscles are completely-extended, and can*not* work-properly. In-addition, a-*combination* of the-high-force-requirement, and the-poor working-posture, adopted, by-the-worker, is likely tolead to-an-increase in MSDs, and the-likelihood of slip, trip, and fall-accidents. As Todd & James (2004); Menz *et al.* (2003), and Cordero *et al.* (2003), all agree, that the-potential, for loss of balance, while pushing and pulling, is considerable.

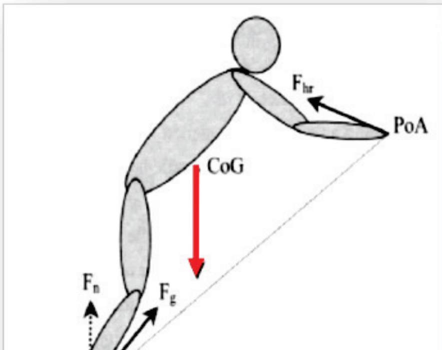
On-the-other-hand, when using strength-measures, to-assess the-potential for overexertion, during handling-tasks, it-is-important to-identify the-weakest-muscle-groups, used in-the-task (Rodgers *et al.,* 1986), as these tend to-fatigue quicker, and are stressed to a-higher-degree of their-maximum-capability. For a-majority of handling-tasks, the 'weakest-link' or limiting-muscle-groups are considered-to-be those, associated-with grip, and shoulder-movements (Rodgers *et al.,* 1986). Likewise, Konz & Johnson (2004) consider arm and shoulder-capability (*not* the-lower-back) to-be the-limiting-factor, for pushing and pulling exertions, when: (1) Activity is repetitive (local-muscle-fatigue) ; (2) Posture is poor; (3) Pushing, with the-arms fully-extended (arm-strength is greatest at ½ reach-distance, drops at ¾ reach-distance, and is lowest at reach-distance); (4) Pushing or pulling, with one-arm; (5) Pushing or pulling, above the-shoulder, or below the-hip; (6) Kneeling (reduces capability by about 20%, compared to-standing); and (7) Seated (reduces capability by about 40%, compared to-standing).

The-posture used, while pushing, is defined, largely, by the-height of the-handholds, and the-location of the-feet. A-worker is able to-generate the-greatest-push-force, when the-feet are separated, one-foot some-distance, ahead of the-other (e.g., Figure 3). It provides leverage, for generating pushing-forces and it has-been-suggested, that workers-feet should-be spread-out, rather than planted side-by-side (Marras & Karwowski, 1999). In this-posture, the-rear-foot, and sometimes the-front-foot, as-well, may-be behind, the-body's center of gravity. Foot-placement influences stability (balance) of the-body. Thus, if the-operator loses his-footing or handhold, a-fall can-occur. Forces, which require this-level of exertion, should-be avoided, in pushing-tasks, especially if the-task is repetitive. Such-high-forces will-also be-beyond the- safe-performance of many-workers.

In-addition, from a-biomechanical-perspective, large-pushing and pulling-forces, may produce large-stresses to-both; low-back, as-well-as, shoulder-joints. Only a-few-investigators, however, have quantified-stresses to-both; low-back and shoulder-joints, from pushing and pulling of loads (Hoozemans *et al.,* 2004; Schibye *et al.,* 2001; de Looze *et al.,* 2000). The-study, hence, recommended to-conduct further-study on quantified-stresses to-both; low-back and shoulder-joints, from pushing and pulling of loads, at the-department.

Observing the-worker's posture, it was noted, that pushing-actions were strongest, when the-worker's feet were placed, as-far-back as-possible. This-observation is in-accord with Kumar *et al.* (1995), who pointed-out, that the-maximum pushing-force increased, by placing the-feet-further-away, from-the-point of application, of the-force, or by-placing one-foot in front of the-other.

On-the-other-hand, to-determine mechanical-stress, on the-musculoskeletal-system, biomechanical- models can-be used. The-models are relatively-simple-representations of the-human-body, such-as in-Figure 4, where average-proportions and anatomical-structures of human-body are obvious, clear, and understandable. Muscle-force is used, to-direct the-exerted-force in-directions other-than at right-angles, to the-foot-hand-line (F_{hr} in Figure 4), which is determined by distribution of body-weight (Grieve, 1979).



CoP = centre of pressure of the-ground reaction-force; (*Fg*) at the-feet; *Fn* = normal-forces;
Ff = friction-forces; *CoG* = centre of gravity; *PoA* = point of application of the-hand reaction-force (*Fhr*).
Figure 4: Free-body-diagram of a-pushing-subject.

A-model of the-human-body, with linked-segments, is also-used, to-calculate net-moments, around joints (De Looze *et al.,* 2000). As-mentioned-earlier, there *must* be enough-traction, or friction, at the-feet, for the-worker, to-successfully-apply the-push or pull-force, without slipping; next-section was focused on friction.

4.2. Frictional-forces

Friction affects an-individual's ability, to-push or pull, an-object, and subsequent-risk of MSDs (Maikala *et al.,* 2009). For pushing and pulling, of non-wheeled-objects, the-amount of friction, developed at the-interface, between an-object and the-support-surface, determines how-much horizontal-force is required (*Freq*), to-move the-object. The-magnitude of the-required-horizontal-force, needed to-move an-object, across a-surface, is defined as: the-product of the-coefficient of static-friction (μS), multiplied by the-normal-force (force, exerted perpendicular to-the-surface) between the-object and the-supporting- surface. For wheeled-objects, the-force, required for movement, is determined by the-friction, between the-wheel and axle, and the-rolling-resistance, between the-wheel and the-floor (e.g., carts typically-require greater-pushing or pulling-force, on thick-carpet, than on smooth-concrete). From a dynamics-standpoint, the-speed, of push or pull, as-well-as the-size and type, of wheel, may-also-affect the-required horizontal- force, needed to-move an-object.

Foot-traction also-affects a-person's ability to-generate muscle-force, needed to-push or pull, an-object, as-well-as the-duration of force-exertion, and the-body-posture, necessary to-maintain body-balance (Maikala *et al.,* 2009; Ciriello *et al.,* 2001; Chaffin *et al.,* 1999). For-example, Ciriello *et al.* (2001) reported, that the-maximum-acceptable pushing-forces were significantly-lower, on low-coefficient of friction (COF) surface (COF = 0.26, initial-force 41% lower and sustained force 38% lower), as-compared-to-those on high-friction-surface (COF = 0.68). In-order-to-provide sufficient-pushing or pulling-force, without the-risk of slipping, a-person needs good-shoes and non-slip flooring.

Friction-forces, at the-foot or floor, are one of the-most-important, yet, often, the-most-overlooked, factors in pushing and pulling-tasks. Isaac Newton, observed the-physical-law that for every-force on a-body, there is an-equal and opposite-reaction-force. In the-case of pushing, whatever force is applied, to the-equipment, by the-hands, must be-reacted-to by an-equal-force, at the-foot-floor-interface. Furthermore, if a-worker has limited-traction, at the-feet, they are unable to-safely-optimize their-posture, by-leaning into-the-equipment, because their-feet will begin to-slip, and the-worker may completely-lose-balance, and fall.

On-the-other-hand, Figure 3 also-specifies major-factors, which define how-much-resistance wheeled-equipment will-produce, and how-much-force, an-operator will-be-able to-generate and apply. These- factors also-affect a person's ability to-safely and effectively complete a-pushing or pulling-task. The-following-factors (Load characteristics/factors; Equipment-characteristics; Individual/human-factors; and Workplace, task, and environment-characteristics) were discussed in the-subsequent-sections.

4.3. Factors, affecting push and pull.

4.3.1. Load characteristics/factors.

Early-studies by Datta *et al.* (1983) revealed, that as-load-weight increased, so did the-demand, placed on the-cardiovascular and pulmonary-systems, when pulling-handcarts. Later, Dempsey (2003) found similar-responses, for wheeled-cages. In-practical-terms, Kingma *et al.* (2003) suggested that the-centre of mass, of the-load should-be close, to the-wheel-axes, and kept as-low as-possible. Weight of the-load, however, is just one of the-factors; others include: type of material, transported; and unit-load of material, moved.

MH, often, involves, so-called 'bulk-materials', which are powdery, granular, or lumpy, in-nature, and are stored in-heaps. Examples of bulk-materials are: *minerals* (ores, coals etc.); *earthly-materials* (gravel, sand, clay etc.); *processed-materials* (cement, salt, chemicals etc.); *agricultural-products* (grain, sugar, flour etc.); and other-similar-materials. Major-characteristics of bulk-materials, so-far as-their-handling is concerned, are: lump-size, bulk-weight, specific-weight, moisture-content, flow-ability (mobility of its- particles), angles of repose, abrasiveness, temperature, proneness-to-explosion, stickiness, fuming or dusty, corrosivity, hygroscopic-properties, etc. (Apple, 1972; Bolz & Hagemann, *ed*.).

On-the-other-hand, materials, transported in a-single-trip, are called 'unit-loads'. *A-unit-load* is either; a-single-unit of an-item, or multiple-units, so-arranged, or constrained, that they can-be-handled as a-single-unit, maintaining their-integrity. Unit-load have-been-classified, by BIS, specification-number IS 8005:1976(2), based on: (1) *Shape of unit loads* (rectangular, cylindrical, pyramidal/conical, and spherical); (2) Typical or *usual-forms* like: pallets, plate, containers, bales, and sacks; (3) *Irregular-forms*, like objects with flat-base-dimension smaller, than overall-size, loads on rollers/wheels, and uneven-shapes; (4) *Position of Centre of Gravity (stability)* of load**;** (5) *Mass of unit load* (in 10 steps from 0-2.5 kg to-more-than 5000 kg); (6) *Volume per unit* (in 10 steps, from 0-10 cm^3 to-more-than 10 m^3); (7) *Type of material* in-contact with conveying-system like: metal, wood, paper/cardboard, textile, rubber/plastics, glass, and other-materials; (8) *Geometrical-shape* (flat, concave, convex, irregular/uneven, ribbed, etc.); (9) *Physical-properties of base-surface of unit-load* (smooth, slippery, rough, hard, or elastic, etc.)**;** (10) *Specific physical and chemical properties* (abrasive, corrosive, dust-emitting, damp, greasy/oily, hot, cold, fragile, having sharp-edges, inflammable, explosive, hygroscopic, sticky, toxic, obnoxious, radioactive, etc.); and (11) *Loads sensitive to:* pressure, shock, vibration, turning/tilting, acceleration/deceleration, cold, heat, light, radiation, damp, etc.

Unit-loads can-be used for-both; in-process-MH, and distribution (receiving, storing, and shipping). Advantages of unit-loads are, that: (1) more-items can-be-handled, at the-same-time (thus reducing the-number of trips, required, and, potentially, reducing handling-costs, loading and unloading-times, and product-damage);

and (2) it enables the-use of standardized-MH-equipment (Apple, 1972).

Limitations of unit-loads include the-following: (1) the-negative-impact of batching, on-production system-performance; (2) the-time, spent forming, and breaking-down the-unit-load; (3) the-cost of containers/pallets, and other-load-restraining-materials, used in the-unit-load, and (4) the-cost of returning empty-containers/pallets, to-their-point of origin (Apple, 1972).

4.3.2. Equipment characteristics

Important-characteristics of mechanical-aid-equipment could-be-summarized, as-follows: (1) caster/wheel design-specifications (wheel/castor-size, and number of wheels/castors); (2) handle-type, orientation (angle), height, and handle-diameter; and (3) overall cart-size, weight, and stability; among-others.

As-discussed-earlier, when two-surfaces, are in-contact, *friction* will resist-movement, between-them. In 'ideal' conditions, which exist, primarily, in-theory, a-laboratory, or other highly-controlled environments, a-hard, smooth, wheel-rolling, on a-hard, smooth-surface would-experience the-least-resistance to-rolling. Other-factors including: diameter, tolerance in the-round (concentricity), material-resilience, and energy-loss, affect rolling-resistance, as-well. In-realistic operating-environments, however, these-perfect conditions rarely, if ever, exist.

Using hard-wheels, under typical-conditions will, often, result in-higher-rolling-resistance, increased noise, and vibration.

In a-wheel or caster-system, there are three-locations, where friction can-act, to-resist-movement, increasing the-required-push-forces: (1) in the-axle-wheel interface; (2) in the-swivel-housing (for swivel-casters); and (3) at the-ground-wheel-interface, when a-wheel is slid or pivoted, on a-surface. Moreover, rough or uneven-surfaces, debris, and other-contaminants, can-create physical-barriers, to rolling.

In-general, the-harder the-rolling-wheels, of a-cart, and the-harder the-surface, over which the-cart rolls, the-less pulling or pushing-force will-be-required, to-move the-cart (Das *et al.,* 2002; Laursen & Schibye, 2002; Al-Eisawi *et al.,* 1999b). Likewise, the-larger the-wheel-diameter, the-lower the-pushing, or pulling-force, required to-push, or pull, a-cart (Al-Eisawi *et al.,* 1999b; David & Nicholson, 1985). Also, smaller-wheels can-become more-easily-stuck on, or obstructed, by humps, holes, cracks, and other-floor- obstructions, as-compared-with larger-wheels (Konz & Johnson, 2004). Further, Marras *et al.* (2009) found, that mechanical-aid-devices, with small-wheels, created significantly-greater anterior-posterior (AP) shear- forces, compared with similar-devices, equipped with larger-wheels.

Swiveling of wheels, can affect the-force, required to-move, or stop, a-cart. A-cart, with all-four-swiveling-casters requires more-force, to-turn (Das *et al.,* 2002; Al-Eisawi *et al.,* 1999b). Al-Eisawi *et al.* (1999b) and Drury *et al.* (1975), suggested a-possible-explanation, for this, is that a-person must control both; side-to-side-movement and forward-backward-movement. It-has been also-suggested, that rear-wheels should-swivel, for pushing, and front-wheels, for pulling.

Besides, studies of the-wheel-design indicate, that the-smaller the-diameter, of the-wheel, the-greater the-initial-push or pull-force (Al-Eisawi *et al.,* 1999a). Similarly Jung *et al.* (2005) found, that larger-wheels resulted in 43% reduction in intra-abdominal-pressure. Moreover, according to Lee *et al.* (2007): (1) use a-larger-diameter-wheel, recommended, as increasing the-diameter of the-wheels, generally decreases force-requirements; (2) A harder caster/tire generally decreases force-requirements; (3) A wider-tread generally increases force-requirements; and (4) Pneumatic-wheels should *not* be used, for heavy-loads, as they may compress, and substantially-increase the-force-requirements.

Generally, the-larger the-wheel, or caster-diameter, the-easier it-will-be to-start, and keep the-device rolling, and to-negotiate flooring-imperfections. Steering in tight-quarters, however, will-be relatively- harder, with large-casters, or wheels. The-unit will steer easier, if swivel-casters are installed, at the-end, from which the-operator pushes or pulls, and directionally fixed-casters are provided, at the-opposite-end. If the-handling-device will-be-left, unattended, and has the-potential-to-roll, it should-be equipped-with one or more locking or braking-casters. Wheel or caster-composition selection is a-function of: the-type-flooring; the-unit will traverse; the-maximum-load-capacity; noise, produced while moving; and environmental-considerations.

On-the-other-hand, handle-height is an-important-parameter, and it affects: (1) force, exerted on-the-cart, to-initiate and sustain-movement, (2) maximum-voluntary-strength, (3) compressive and shear-loading of spinal-discs; and (4) stresses to the-shoulder-joints, leg-muscles, and the-back. Handholds are also-important, because they send a-clear-message, to-the-worker, regarding where and how, to-apply force, to-the-equipment, and what-posture to-assume. Currently, however, there is *no* agreement, on-the-exact handle-height, as-well-as other-handle-parameters.

For-example, Dempsey (2003) and Chaffin *et al.* (1999), reported, that the-lower the-handle-height, the-greater the-pushing or pulling-strengths. Hoozemans *et al.* (2004); McGill (2002); and Van der Beek *et al.* (1999), however, agued, that pushing objects, with low-handle-height requires leaning-forward, and can-produce high-compressive and shear-forces, on the-low-back. Kumar (1995), however, identified, that both; isometric and iso-kinetic-strengths, were the-lowest, at the-lowest-handle-height. Moreover, Al-Eisawi *et al.* (1999a) found *no* statistically-significant-differences, in exerted-force, between the three-handle heights (they studied), for a-cartload of 73 kg.

In-contrast, Lee *et al.* (1991) concluded, that optimum-handle-height is specifically 91cm, from the-floor, for pushing, and 152cm, for pulling-tasks. Marras & Karwowski (1999) recommended elbow-to-hip height, for pushing, and hip-to-knee height, for pulling tasks. Lett & McGill (2006); and Hoozemans *et al.* (2004) recommended, that handles should-be at-shoulder-height, for two-handed-pushing, as this-height allows greater-lumber-flexion and use of body-weight, to-assist with the-push. On the-other hand, the-optimum-height, for pulling was waist-height. Yet, Granata & Bennet (2005) pointed-out, that spinal-stability was the-lowest, when pushing, at-shoulder-height. In-addition, some-researchers argue the-optimum-handle-level is 70% to 80% of shoulder-height, or about 100cm, for-men, and 90cm, for-women.

Regarding shape and width of the-handle, the-operator should-be-able to-grip the-handle with a-power-grip, meaning the-fingers and the-palm, of the-hand, should-be in full-contact with the-handle (Hoozemans *et al.,* 2004). Moreover, a-handle, generally, should-be-shaped so, that it does *not* concentrate pressure, on any-specific-part of the-hand (i.e., it should *not* have sharp-edges, pronounced-ridges, etc.), to-avoid contact-stress and MSIs.

With regard to handle-design, Jansen *et al.* (2002) suggested two-vertical-handles, over a-horizontal- handle. Such-handles allow the-operator, to-place their-hands, at an-appropriate, for them, height. To-accommodate workers, of various-heights, vertical-handles, for pushing, should-cover a range of 76-120cm, while for pulling the-range is from 66cm to 100cm, above the-rolling-surface.

Moreover, handles should-be angled, to-decrease steering-errors (Wissenden & Evans, 2000), and the-force-exertion-direction should-be-close to horizontal, for efficient-pushing and pulling (de Looze *et al.,* 2000). Besides, Marras *et al.* (2000) argued, that handle-*angle* is important, as it would-have an-impact on joint-loading, and they recommended, that optimal-handle-angle is 35° from the-axis, through the-back of a-trolley, as it resulted in the-lowest-initial-forces.

The-above-narrative illustrated, that, currently, there is *no* consensus, on the-optimum-height and exact-angle of the-handles, which is 'correct; for all, including short and tall-people, therefore, it-is only logical, that, the-handles should-be-adjustable, or vertical.

4.3.3. Individual/human-factors

Individual/human-factors, affecting push and pull-capability, are (Darcor & Ergoweb, 2001): Anthropometry (height, weight); age; gender; strength; posture; and physiological-aerobic-capacity.

Workers could have different-characteristics and capabilities. For-example, a-tall-worker might have-to-adopt an-awkward-posture, to-push a-trolley, with low-handles, while a-shorter-worker may-have difficulty seeing, over the-load. An-increase in-body-weight, on-the-other-hand, resulted in an-increase of the-maximum-push or pull-forces (Ayoub & McDamel, 1974). All-this should-be considered, by the-supervisors, when deciding who is going-to-transport the-load.

The-work-capacity depends on the-whole of physical, cognitive, and mental-characteristics and capacities, of a-worker; for-instance, muscular-strength, body-weight, gender, and the-motivation to-use the-capacities (Lee *et al.,* 2007). Resnick & Chaffin (1995) found, that factors such-as: motivation, interpretation of instructions, balance-control, and fear of slipping, all-played an-important-role in peak-force-magnitudes, during pushing and pulling-activities. De Looze *et al.* (2000) concur, arguing that force-direction is constrained, by the-need to-maintain-balance, and to-prevent the-individual, from slipping.

On-the-other-hand, operator-knowledge, and training, is paramount; training on how to-move the-cart, safely, has-been-shown, in-some-studies, to-lower the-force on the-body. It-is therefore, recommended, that operators should: (1) be-trained on appropriate-body-positioning, for the-type of cart, and load, being handled; (2) receive training on how to-safely-maneuver heavy-loads; and (3) transport loads, at an-appropriate-trolley-speed (recommended-speeds should-match a-typical-walking pace of 3-4 km/h) (Darcor & Ergoweb, 2001).

4.3.4. Workplace, task, and environment characteristics

Task-factors include (Darcor & Ergoweb, 2001): Load; load-distribution; direction of motion; frequency; distance, moved; speed; movement-initiation force-requirements; sustained-motion force-requirements; direction and nature of movement; and duration of pushing or pulling-task. On-the-other-hand, floor or ground-factors incorporate: surface-characteristics; slope; and contaminants.

Confined-spaces and narrow-passages, or doorways, could provoke a-tripping, trapping, or abrasions-injury. Aisles, ideally, should be-wide-enough, for the-operator's body, to-safely stand-behind the-trolley, at-all-times; if it-is *not* possible, like in-this-study, load-weight may-need to-be-reduced, in-tight- aisles, doorways, or corners, and aisles should-be-kept clear of clutter.

Besides, more-force is required to-move the-same-weight up-ramps, as-well-as to-slow-down a-fully-loaded-cart, while-moving down-ramps. For-example, Van der Windt found increased-mechanical- load, on the-lower-back, and the upper-extremities, when pushing a-wheelchair, on a-slope, was compared to-pushing on a-flat-surface. It has-been-suggested, that floor-slopes should-be-less than 3.5% grade (2°) (Lawson *et al.,* 1993;

Eastman Kodak Co., 1986; Miller, 1985). Pushing or pulling an-object, up or down, a-ramp changes the-relative-contribution, of the-horizontal and vertical-components, of applied-force, which can-increase, or decrease the-pushing or pulling-force, needed to-move the-object. The-study recommends, to-use winches, for large-ramps; If multiple-ramps are present, include a-hand or foot-brake, on the-cart, to-help the-operator control heavy-loads, and consider using powered-carts, to-reduce the-force, required.

In-addition, floor-characteristics are very-important, as damaged, uneven, or etched-floors, create hazards, of catching wheels, or castors, in-them. Besides, slipping, and tripping, is affected, greatly, by the-foot-floor-interface. Floor-surfaces made of concrete, metal, or rubber-matting, all have different frictional-properties. Floors that are dusty, dirty, oily, or wet, will-reduce the-ability of the-handler to-maintain-traction. Without-friction, the-worker will-need-to-exert *excessive*-force, to-move the-load, and may slip, trip and/or fall. Floor-contaminants can-reduce the-traction, between the-shoes and floor, making-it more-difficult, and even, dangerous, for the-operator, to-apply the-necessary push or pull-forces, and may-also-interfere with caster-function. Therefore, floors should-be-kept, in good-repair; and also be-clean, free of debris, dirt, dust, miscellaneous-liquids, or oil, or chemical-spills. If floors are *very*-uneven, as in-some-places of the-subject-department, powered-carts should-be considered.

Furthermore, work-organization and psychosocial-factors are of importance, such-as: high-workload demands, short-deadlines, and lack of control and working-methods; poor-communication with managers and employees; and any-organization ‘change’ can have an-effect on the-performance of workforce.

4.4. Recommendations to-control hazards and risks, related to pushing and pulling.

The-National-Institute of Occupational-Safety and Health (NIOSH, 1997), U.S.A., as part of an-ergonomics ‘tool-box’ for workplace-evaluations of musculoskeletal-disorders, have-proposed a-number of design-principles, for pushing and pulling-tasks. A-hierarchy of four-design-principles is considered important, for reducing the-risks, associated with pushing and pulling:

(1) *Eliminate* the-need to-push or pull (by using powered-conveyors, powered-trucks, lift-tables, slides, or chutes);

(2) *Reduce the-force,* required to-push or pull (by reducing size and/or weight of the-load; using four-wheeled trucks, or dollies; using non-powered-conveyors; ensuring wheels and castors, on hand-trucks, or dollies, have: (a) Periodic-lubrication of bearings; (b) Adequate-maintenance; (c) Proper-sizing (provide larger-diameter-wheels and castors); (d) Proper-maintenance of the-floors, to-eliminate holes and bumps; and (e) Surface-treatment of floors, to-reduce friction;

(3) *Reduce the-distance* of the-push or pull (Move receiving, storage, production, or shipping-areas, closer to-work-production-areas; Improve the-production-process, to-eliminate unnecessary-materials handling-steps); and

(4) *Optimize the-technique* of the-push or pull (Provide variable-height-handles, so that both; short and tall-employees can-maintain an-elbow-bend of 80 to 100 degrees; Replace a-pull with a-push, wherever possible; Use ramps with a-slope of less-than 1:10 (9°)).

In-addition, the-following-practices were-recommended: (1) The-composition, frequency, and duration of the-task should-allow adequate-physiological-recovery-time, for the-worker; (2)The-workers should-have some-degree of autonomy, in how they can-organize their-work. It-is suggested, that job- enrichment, job-enlargement, and job-rotation, may have a-key-role, to-play in-providing recovery, variety, and maintaining-levels of production-output, as-long-as the-tasks involve the-use of different-muscle- groups; (3) Operators should-be-trained, in how to-safely-perform each-task, and how to-recognize hazardous-workplaces, tasks, and equipment-conditions; (4) Operators should-be-aware of the-necessary procedures and communication-channels, through-which to-report and correct such-hazards; (5) Equipment and facilities must-be-properly-maintained, for safe-usage, and defective or damaged-equipment, must-be removed from use, immediately; (6) The-equipment purchase-process should-be-based-upon clear-task- requirements, and thus, should select-equipment, suitable for the-specific-workplace and task-conditions.

Besides, ergonomics-analysis-tools could-be also helpful, for example three-Dimensional Interactive Application (CATIA) software is one of the-ergonomics-analysis-tools, that have-been-applied, to-analyze pushing and pulling-activities, of workers, while performing tasks, in-awkward-posture (see Govindu & Reeves, 2012; Daraiseh *et al.,* 2010; Sheikhzadeh *et al.,* 2009; Landau *et al.,* 2008; Vieira & Kumar, 2007). Besides, Matebu & Dagnew (2014) recommended the-3D Static-Strength Prediction-Program (3DSSPP) software; manual-material-handling-tasks can-be-designed and analyzed, by considering different-aspects of ergonomic-principles, to-minimize the-relevant, to pushing and pulling, musculoskeletal-disorders.

5. Conclusion and Recommendations.

The-current-article provided a-laconic-discussion of important-factors, relevant to-evaluating pushing or pulling-tasks. The-study revealed that now, it-is unclear whether; push or pull, is preferable. Likewise, there is *no* consensus on *exact*-handle-height of a-trolley/cart.

Understanding the-task-requirements, operating-environment and conditions, and the-people, that will-perform the-work, is paramount. By studying a-task, or job, in-detail, and cautiously-harmonizing equipment and people, with those-demands, MH-equipment with very-heavy-loads, can-be pushed, or pulled, safely and efficiently.

This-study also-found, that pushing and pulling-tasks is an-everyday-occurrence, at the-department. During such-tasks workers, conducted: push or pull very-heavy-loads; repeatedly; using equipment, that was *not* properly-maintained, and/or with *no* brakes, on uneven-floor-surfaces, and in-confined-spaces, and hence, they had-to-assume awkward-postures, and apply significant-force to-move, such-equipment, with the-load. Such-practices are qualified as hazards and risks of MSDs and MSIs, and should-be-eliminated, re-designed, or exposure to-such-hazards, should-be-reduced.

To-reduce the-risks, associated with pushing and pulling, general, well-articulated NIOSH recommendations, were given, as hierarchy of four-design-principles,: (1) *Eliminate* the-need to-push or pull; (2) *Reduce the-force,* required to-push or pull; (3) *Reduce the-distance* of the-push or pull; and (4) *Optimize the-technique* of the-push or pull.

In-addition, the-study has put-forward several-*tailored*-recommendations, which should-be-useful, to-employers and practitioners, who design and analyze, pushing and pulling-tasks, at the-department, and in-the-industry, at-large. The-recommendations of undemanding-measures can-be-taken, to-ensure the-risks, associated with pushing and pulling, mechanical MH-equipment, are minimized, as-follows:

1) Pushing and pulling-tasks should-be designed to-restrict (1) speed; (2) maximum-stacking- heights of trolleys, to-improve visibility and posture, for users, and reduce the-weight of the-load;
2) To-reduce risks MSDs and MSIs, workers, who-operate mechanical-aids, such-as carts, dollies, lift-trucks or pallet-jacks, should-be fully-trained, in their-use, and to-use correct-body-mechanics and postures, for pushing and pulling;
3) Where there is a-need-to-move heavier-loads, over longer-distances, using powered-trucks, or a-powered-conveyor-system should-be-considered;
4) Automatically-opening-doors should-be-provided, if possible;
5) For the-factory-management to-provide, and for the-workers to-use, personal-protective- equipment, where needed, such-as: gloves, with good-grip, and steel-toed-boots, where appropriate;
6) Maintenance-department should install brakes, on MH-equipment, where missing;
7) Good-housekeeping and proper-regular-maintenance of MH-equipment and floors, should-be ensured by the-management; and
8) Further-study on quantified-stresses to-both; low-back and shoulder-joints, from pushing and pulling of loads, at the-department.

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