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Psychophysical basis for maximum pushing and pulling forces: A review and recommendations

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Abstract

The objective of this paper was to perform a comprehensive review of psychophysically determined maximum acceptable pushing and pulling forces. Factors affecting pushing and pulling forces are identified and discussed. Recent studies show a significant decrease (compared to previous studies) in maximum acceptable forces for males but not for females when pushing and pulling on a treadmill. A comparison of pushing and pulling forces measured using a high inertia cart with those measured on a treadmill shows that the pushing and pulling forces using high inertia cart are higher for males but are about the same for females. It is concluded that the recommendations of Snook and Ciriello (1991) for pushing and pulling forces are still valid and provide reasonable recommendations for ergonomics practitioners. Regression equations as a function of handle height, frequency of exertion and pushing/pulling distance are provided to estimate maximum initial and sustained forces for pushing and pulling acceptable to 75% male and female workers.

At present it is not clear whether pushing or pulling should be favored. Similarly, it is not clear what handle heights would be optimal for pushing and pulling. Epidemiological studies are needed to determine relationships between psychophysically determined maximum acceptable pushing and pulling forces and risk of musculoskeletal injuries, in particular to low back and shoulders.

Keywords

Maximum acceptable pushing and pulling forces (MAFs); Regression equations to estimate MAFs; Factors affecting pushing and pulling forces; Ergonomic recommendations

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1. Introduction

Pushing/pulling tasks are common in industries and services such as shipping and receiving, moving, warehousing, garbage collection, agriculture, farming, fire fighting, construction, airlines, gardening and nursing (Winkel, 1983; Hoozemans et al., 1998; van der Beek et al., 1993; Baril-Gingras and Lortie, 1995). It is estimated that about 50% of manual material handling tasks performed in certain industries require pushing and/or pulling maneuvers (Baril-Gingras and Lortie, 1995). It appears that lifting and lowering tasks are commonly being replaced with pushing and pulling tasks in industry (Resnick and Chaffin, 1995; Al-Eisawi et al., 1999a; Laursen and Schibye, 2002; Kingma et al., 2003; Ciriello, 2004; Jung et al., 2005). Thus, prevalence of pushing and pulling activities may be higher than these statistics suggest. Approximately, 80% of carts are pushed more than once per day and 30% are pushed more than 10 times per day (Mack et al., 1995).

Pushing and pulling of carts and objects exposes workers to two types of hazards: (i) stresses to the musculoskeletal system from applied hand force, and (ii) accidents due to slipping or tripping (Chaffin, 1987; Grieve, 1983). Cross-sectional epidemiological studies show that pushing and pulling activities are associated with shoulder and low-back pain. Evidence for musculoskeletal disorders to other parts of the body is lacking. Epidemiological studies show that 9–18% of the low-back injuries are associated with pushing and pulling (Snook, 1978; Frymoyer et al., 1980; NIOSH, 1981; Damkot et al., 1984; Klein et al., 1984; Metzler, 1985; Harber et al., 1987; Pope, 1989; Lee et al., 1992; Garg and Moore, 1992; Meyers et al., 1993). However, studies on quantified physical exposure from pushing/pulling tasks and low-back pain are lacking. A few studies have reported a relationship between pushing/pulling and shoulder pain, such as increased shoulder pain from pushing/pulling wheeled equipment (van der Beek et al., 1993; Hoozemans et al., 2002a,b; Harkness et al., 2003), pushing/pulling heavy weights (Harkness et al., 2003), pushing against a bar at waist height while walking on a treadmill (Garcin et al., 1996), and pushing against a high handle (Abel and Frank, 1991).

The objective of this paper was to summarize the psychophysical literature on pushing/pulling of carts and to make recommendations for acceptable pushing/pulling forces based on psychophysical studies.

2. Psychophysics

Psychophysics is a branch of psychology studying relationships between sensations and their physical stimuli. According to psychophysical theory, the perceived strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by a power function ($S = kI^n$) (Stevens, 1960). Pushing/pulling of carts involves application of force and muscular effort. Both the application of physical force and perception of muscular effort have been shown to follow the psychophysical power law (Eisler, 1962; Borg, 1970). A value of 1.6 was suggested for the exponent (n) both for muscular effort and force (Eisler, 1962; Borg, 1970), and confirmed by Karwowski and Pongpatana (1989) for typical loads lifted in industry. Many studies have demonstrated the utility of psychophysics in determining maximum acceptable weights, forces and workloads (Snook and Irvine, 1969; Snook, 1978;

Ayoub et al., 1980; Garg and Ayoub, 1980; NIOSH, 1981; Mital, 1984; Karwowski and Ayoub, 1984; Garg and Badger, 1986; Ridyard, 1990; Snook and Ciriello, 1991; Waters et al., 1993; Karwowski and Gaddie, 1995). These and other studies have shown that psychophysically determined maximum acceptable weights and forces are reliable and reproducible. Recently, Lett and McGill (2006) reported that psychophysically determined maximum acceptable pushing and pulling forces (Snook and Ciriello, 1991, 50th percentiles population) produced strikingly similar results to those based on biomechanical force limits of 3400 N (Waters et al., 1993) in compression and 500 N (Lett and McGill, 2006) in shear for the spinal discs.

Snook (1978) reported that properly designing manual handling jobs using psychophysically determined maximum acceptable weights and forces can reduce up to one-third of industrial back injuries. Similarly, Herrin et al. (1986) reported a strong negative correlation between predicted minimum percentages capable based on psychophysical data and incidence rates for low back, musculoskeletal, overexertion and contact injuries. The authors concluded that the percentage of population capable of performing the most stressful aspect of a job based on either psychophysically determined maximum acceptable weights or static strength is perhaps the best simple index to predict risk of low-back and musculoskeletal injuries.

Advantages of the psychophysical approach include: (i) ability to realistically simulate industrial work, (ii) allows study of both intermittent as well as repetitive tasks, (iii) psychophysically determined maximum acceptable weights (MAWs) and forces (MAFs) are based on integrated response of the body from the worker (Karwowski and Ayoub, 1984), (iv) MAWs and MAFs are reproducible, and (v) MAWs and MAFs are predictive of back injuries (Snook, 1978; Herrin et al., 1986; Zurada et al., 2004). Disadvantages of the psychophysical approach include: (i) approach is subjective and relies upon self-report from subjects (Karwowski et al., 1999), (ii) at high frequency of exertion MAWs and MAFs exceed those based upon physiological criteria (Ciriello and Snook, 1983, 1993), (iii) the method is time consuming and expensive for collecting data for very infrequent tasks, and (iv) at low working height and/or for very infrequent tasks, MAWs and MAFs may exceed recommended levels of compressive and shear forces on spinal discs.

3. Pushing/pulling

3.1. Definition of pushing and pulling

Pushing/pulling is characterized by exertion of hand force in a horizontal direction – away from the body for pushing and toward the body for pulling. 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/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 certain 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. 1988), overcomes a bump or obstacle in the path of the object being pushed or pulled, or when pushing/pulling from one level to another level such as pulling an object on a stair. Lastly some pushing and pulling activities may not result in movement of an object.

Pushing/pulling forces are characterized by (i) initial force required to start the movement of an object, (ii) sustained force – a lower force required to sustain the movement – and (iii) stopping force required to stop the movement of an object. Most of the published literature in ergonomics deals with initial and sustained forces for pushing and pulling.

3.2. Pushing/pulling characteristics in industry

Ciriello et al. (1999) analyzed 25,291 manual materials handling tasks including 1879 pushing tasks and 1866 pulling tasks. According to this 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 <1.5 m to >30.5 m with 24% of tasks requiring a pushing distance between 1.5 and 6.1 m 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 were performed between 76 cm (about knuckle height) and 114 cm (about elbow height). Pulling data from Ciriello et al. (1999) showed that pulling characteristics were comparable to pushing characteristics.

3.3. Pushing v. pulling

The results are inconsistent when comparing maximum pushing strength with maximum pulling strength. Keyserling et al. (1980) and Daams (1993) 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, Chaffin et al. (1983) and van der Beek et al. (2000) reported that pushing strengths were higher than pulling strengths. These inconsistencies between pushing and pulling strengths might be due to 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/pulling horizontally v. at an angle).

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 (Snook et al., 1970; Snook and Ciriello, 1991; Ciriello et al., 1993; Boocock et al., 2006). 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.

Al-Eisawi et al. (1999a) reported that, on average, pushing required 93.5% of pulling forces for pushing the same cart weights. Pushing results in lower compressive force than pulling (Lee et al., 1991; Hoozemans et al., 2004). Others have reported that pulling tasks as compared to pushing tasks result in lower compressive and shear forces (Lett and McGill, 2006). In a biomechanical study comparing spinal loading for a simple pushing and pulling task, Knapik and 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. At present it is not clearly established whether pushing or pulling results in lower stresses to the workers.

3.4. Factors affecting pushing and pulling forces

3.4.1. Friction—Friction affects an individual's ability to push/pull an object and subsequent risk of musculoskeletal disorders (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 (F_{req}) 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/pulling force on thick carpet than on smooth concrete). From a dynamics standpoint, the speed of push/pull as well as the size and type of wheel may also affect the required horizontal force needed to move an object.

Foot traction affects a person's ability to generate muscle force needed to push/pull an object, as well as the duration of force exertion and the body posture necessary to maintain body balance (Chaffin et al., 1999; Ciriello et al., 2001; Maikala et al., 2009). 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/pulling force without the risk of slipping, a person needs good shoes and non-slip flooring. A slick floor would cause an individual to stand more upright to maintain body balance. On the other hand, the lower the coefficient of friction, the easier the object will slide on a surface (for example: floor, conveyer belt, wheeled cart, etc.).

3.4.2. Grade/Slope—It has been suggested that ramps should be less than 3.5% grade (2°) (Hansson, 1968; Miller, 1985; Eastman Kodak Co., 1986; Lawson et al., 1993). 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.

3.4.3. Wheels—In general, the harder the rolling wheels of a cart and the harder the surface over which the cart rolls, the less pulling/pushing force will be required to move the cart (Hansson, 1968; Eastman Kodak Co., 1986; Al-Eisawi et al., 1999b; Das et al., 2002; Laursen and Schibye, 2002). Similarly, the larger the wheel diameter the lower the pushing/pulling force required to push/pull a cart. (Drury et al., 1975; David and Nicholson, 1985; Al-Eisawi et al., 1999b). 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 and Johnson, 2004). Further, in a study of pushing floor based patient lifting devices, Marras et al. (2009) found that those 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 a cart as well as stop a cart. A cart with all four swiveling casters requires more force to turn (Al-Eisawi et al., 1999b; Das et al., 2002). One possible explanation for this is that a person must control both side-to-side movement and forward–backward movement. It has been suggested that rear wheels should swivel for pushing and front wheels for pulling (Drury et al., 1975; Al-Eisawi et al., 1999b).

3.4.4. Maintenance of carts and floors—Maintenance of the wheels and wheel bearings affect the amount of pushing/pulling force required to move a cart. Das et al. (2002) reported that a cart equipped with ball bearing casters was easier to push/pull than carts equipped with sleeve bearing casters.

Uneven floor surfaces can significantly increase the force required to push/pull a cart. Lawson et al. (1993) reported that ridges between uneven floors in a hospital, such as elevators, ranged between 1 and 2 cm in height, and in some cases up to 5 cm. Pushing and pulling of food carts over these ridges required more than 490 N of force (Lawson et al., 1993). Similarly, moments on the lower back close to 400 Nm have been reported when pulling a four-wheeled trash container over a curb (Jäger et al., 1984; de Looze et al., 1995; Frings-Dresen et al., 1995a,b). Boocock et al. (2006) concluded that a 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.

3.4.5. Weight on the cart—For a given cart and floor surface, as the weight of the cart increases the force required to push/pull a 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 (e.g. hard versus soft), type of axle bearing, flooring surface, handle type and height (affecting magnitude of vertical component of force), and cart acceleration and velocity. It should be noted that while the force required to push/pull a cart is affected by cart weight and load on the cart, it is the magnitude of the force required to push/pull the cart that determines whether a specific push/pull is acceptable. A cart that is not properly balanced requires more force to push/pull and makes it difficult to maintain the direction of movement. The same is true if the wheels are not properly aligned. A load limit of 225 kg for four-wheeled carts and 114 kg for two-wheeled carts has been suggested (Eastman Kodak Co., 1986; Resnick and Chaffin, 1995; van der Beek et al., 2000), but these values do not consider the actual magnitude of the pushing or pulling forces required, and should be used with caution.

3.4.6. Handle height—Ayoub and McDaniel (1974) concluded that the handle height of a cart should be as low as possible and foot distance as large as possible to delay onset of fatigue. Chaffin et al. (1999) reported that the lower the handle height, the greater the pushing and pulling strengths. Based on subjective feeling of fatigue, Kumar (1995) studied pushing and pulling static and isokinetic strengths at three different handle heights (35, 100 and 150 cm). Both isometric and isokinetic strengths were the highest at a handle height of 100 cm and the lowest at 35 cm height. Because of these inconsistencies, it is not clear what handle height(s) result in optimum pushing/pulling strength.

Ciriello and Snook (1983) reported that both the initial and the sustained maximum acceptable pulling forces decreased with an increase in handle height for male subjects. For female subjects initial force showed a decrease with an increase in height, but the sustained pulling force showed a slight increase or no change with an increase in height. For pushing tasks, optimum height for initial force was midway between knuckle and elbow height (as compared to shoulder height and below knuckle height) for males and shoulder height for females. For all practical purposes height had no effect on sustained pushing force both for males and females.

Al-Eisawi et al. (1999a) measured the horizontal force exerted to initiate movement of a cart loaded with two different weights, at three different handle heights. For a cartload of 181 kg, they found the initial horizontal force exerted to push/pull a cart was highest at knuckle height, followed by force at elbow height and it was lowest at shoulder height. They found no statistically significant differences in exerted force between the three handle heights for a cartload of 73 kg. Subjects were instructed to apply the minimum force necessary to initiate cart movement. One would expect that the minimum force required to initiate movement of the cart would be the same irrespective of the handle height (as seen with 73 kg cart). The authors did not offer an explanation for differences in pushing and pulling forces due to handle height when pushing the 181 kg cartload. It could be that subjects chose to use a greater percentage of their body weight at lower heights to help initiate cart movement, thus resulting in greater cart acceleration and exerted forces.

Lee et al. (1991) concluded that optimum handle height is 91 cm from floor for pushing and 152 cm for pulling tasks. Marras and Karwowski (1999) recommended elbow-to-hip height for pushing and hip-to-knee height for pulling tasks. However, pushing objects with low handle height requires leaning forward and can produce high compressive and shear forces on the low back (McGill, 2002; Resnick and Chaffin, 1995; van der Beek et al., 1999; Hoozemans et al., 2004). Hoozemans et al. (2004) recommended that hands should be at shoulder height for two handed pushing. Similarly, Lett and McGill (2006) found that the optimum height for pushing was at shoulder height because 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. van der Woude et al. (1995) recommended 86.5% of shoulder height for pushing wheelchairs. Lee et al. (1992) reported that pushing and pulling at handle heights of 160 cm resulted in the lowest and the highest required coefficient of friction, respectively. However, spinal stability was the lowest when pushing at shoulder height followed by mid-height and it was the highest at waist height (Granata and Bennet, 2005).

Jansen et al. (2002) suggested two vertical handles are preferable over a horizontal handle. Handles should be angled to decrease steering errors (Wissenden and Evans, 2000) and the force exertion direction should be close to horizontal for efficient pushing and pulling (de Looze et al., 2000).

From the above discussions it is clear that handle height is an important parameter in cart design. Handle height affects (i) force exerted on the cart to initiate and sustain movement, (ii) maximum voluntary strength, (iii) compressive and shear loading of spinal discs, and (iv) stresses to the shoulder joints. One would expect that handle height would also have an impact on localized muscle fatigue (shoulders and low back) as well as whole body fatigue (energy expenditure) when pushing/pulling tasks are performed frequently and/or over a large distance. Unfortunately, at this time there are insufficient conclusive data to recommend handle heights that would result in lower strength requirements and lower stresses to low back and shoulder as well as minimum localized and whole body fatigue.

3.4.7. Trunk posture—In order to use their body weight to assist in pushing and pulling objects, individuals tend to lean forward to push and backward to pull. Trunk posture affects forces in trunk muscles (back and abdominal), and compressive and shear forces on spinal discs and stresses to shoulder joints. It is not clear what posture(s) would be optimal to minimize compressive and shear forces on spinal discs as well as stresses to shoulder joints.

3.4.8. Feet—Foot placement influences stability (balance) of the body. It provides leverage for generating pushing and pulling forces and it has been suggested that workers feet should be staggered rather than planted side by side (Marras and Karwowski, 1999).

3.4.9. Pushing and pulling frequency—Several studies have reported that both initial and sustained maximum acceptable pushing and pulling forces decrease with an increase in frequency of exertion (Snook, 1978; Ciriello and Snook, 1983; Snook and Ciriello, 1991).

3.4.10. Pushing/pulling distance—Several studies using a psychophysical approach have shown that both the initial and sustained forces decrease with an increase in pushing/pulling distance (Snook, 1978; Snook and Ciriello, 1991).

3.5. Psychophysical studies on maximum pushing/pulling strengths

There have been a few studies on static and isokinetic pushing/pulling strengths (Ayoub and McDaniel, 1974; Chaffin et al., 1983; Fothergill et al., 1991, 1992; Daams, 1993; Kumar, 1995; Resnick and Chaffin, 1995; Chaffin et al., 1999; Lee, 2007). Herring and Hallbeck (2007) studied maximum voluntary pushing and pulling strengths while seated. Several studies have measured pushing and pulling forces by loading carts and postal cages with fixed amounts of weights (Resnick and Chaffin, 1996; Al-Eisawi et al., 1999a,b; van der Beek et al., 2000; Hoozemans et al., 2001, 2004). Others have reported exerted pushing/pulling forces in a distribution center (Kuijer et al., 2007), forces required to push/pull airline trolleys in aircraft cabins (Glitsch et al., 2007), maximum acceptable trolley loads in aircraft cabins (Glitsch et al., 2007) and maximum acceptable trolley loads (Haslam et al., 2002). These studies provide valuable information on static and dynamic strengths for single exertions and forces required to push/pull carts and weights. However, these studies neither provide sufficient information for designing repetitive pushing and pulling tasks in industry, nor information on how to adjust published static and isokinetic strength values when pushing and pulling distances are large and strengths might be affected by fatigue.

3.5.1. One-handed pulling strength—

Garg and Beller (1990) conducted a laboratory study to determine the effect of pulling speed, handle height and angle of pull from the horizontal plane on one-handed dynamic pulling strength. The dynamic strength of nineteen male subjects for a 1 m pull was measured at four different handle heights (40%, 50%, 60% and 70% of shoulder height), at three different angles above the horizontal plane (15°, 25° and 35°), and at three different speeds of pulling (mean speed = 0.7, 1 and 1.1 m s^{-1}). Among the three variables, pulling speed was found to be the most critical. The mean dynamic strength was 360, 250, and 180 N and the peak strength was 600, 425 and 320 N at 0.7, 1 and 1.1 m s^{-1}, respectively. The strengths decreased with an increase in handle height from 100% of maximum at 40% shoulder height to 83% of maximum at 70% of shoulder height and were the highest at an angle of 25° from the horizontal plane. The handles at 50% and 60% of shoulder height and at an angle of 25° were perceived as being more comfortable than those at other heights and angles ($p < 0.01$).

Garg et al. (1988) reported that one-handed peak and mean dynamic pulling strengths were 55% and 34% of static pulling strengths. Men in the age group 21–34 years had the highest strength and women in the age group 51–71 years the least strength. Dynamic pulling strengths for females were 65% of male strengths. Maximum stresses were perceived on the shoulder and upper arm with a mean exertion rating between fairly light and somewhat hard.

Fothergill et al. (1991) studied one-handed maximum static strengths in all directions in the fore and aft plane. At 1.0 m height, one-handed exertions were significantly lower than two-handed exertions but the difference was smaller at 1.75 m height. Female absolute strength was 65% of male strength.

4. Maximum acceptable pushing and pulling forces

As far as maximum acceptable pushing and pulling forces are concerned, Snook, Ciriello and their colleagues at the Liberty Mutual Research Institute have conducted most of the studies reported in the literature (Snook et al., 1970; Snook and Ciriello, 1974a,b; 1991; Snook, 1978; Ciriello and Snook, 1983; Ciriello et al., 1990; Boocock et al., 2006). 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. Workers were asked to select a workload that could be sustained for 8 h without straining themselves or without becoming unusually tired, weakened, overheated or out of breath. In a few studies oxygen uptake (VO_2) and heart rate (HR) were also measured. Subjects were given control of force; all other task variables, such as distance moved, task frequency, hand height, etc., were controlled. Pushing and pulling tasks were simulated on a specially controlled treadmill. The treadmill was powered by the subject as he or she pushed or pulled against a stationary bar. The subject controlled the resistance of the treadmill belt by varying the amount of electric current. A load cell on the stationary bar measured the horizontal force being exerted. Subjects were second-shift workers from a local industry.

In 1978, Snook first reported a comprehensive database for maximum acceptable pushing and pulling forces by integrating the results from his previous studies. Later, Ciriello and Snook (1983) investigated effect of task frequency on maximum acceptable pushing and pulling forces using 12 female and 10 male subjects. Frequency varied from once every 5 s to once every 8 h. Maximum acceptable forces for females were significantly lower but were proportionately similar to the maximum acceptable forces for males reported earlier (Snook, 1978). Maximum acceptable forces decreased as frequency increased. The authors concluded that the forces for exertions performed once every 5-min. and once every 30-min. were overestimated in the original tables (Snook, 1978). Further, at very high frequencies (faster than 4.3 exertions/min.) values for maximum acceptable forces were associated with oxygen uptake values that exceeded physiological criteria for an 8 h day (33% of VO_{2max}).

In another study, Ciriello et al. (1990) investigated the effect of task duration (hours or exposure per day) on maximum acceptable forces. In this experiment the subjects continuously applied pushing/pulling forces against a stationary bar on a particle brake (MBP) treadmill for 4 h with a 20 min break after 100 min. All experiments were carried out at a frequency of 1 push (or pull)/min. For males, initial and sustained pushing and pulling forces selected after 40 min were not statistically different from the forces selected after 4 h. For females, initial and sustained pulling forces for 7.6 m pull selected after 4 h were 84.4% and 75.3% of those selected after 40 min; both values were statistically lower. Mean heart rates after 4 h ranged from 86 to 108 beats/min for males and 88 to 106 beats/min for females.

4.1. Pushing/pulling a cart v. pushing/pulling against a handle bar on a treadmill

Ciriello (2004), Ciriello et al. (1999, 2004, 2007, 2010) and Maikala et al. (2009) investigated the effect of two techniques on maximum initial and sustained pushing forces acceptable to female and male workers, respectively, using (i) a MBP treadmill and (ii) a high-inertia pushcart. For females, the maximum acceptable initial and sustained pushing forces determined on the high-inertia cart were not statistically different from those forces determined on the MBP treadmill (Ciriello, 2004; Ciriello et al., 2010). In his 2004 study of female workers, Ciriello found that the maximum acceptable initial force was 9.8% higher and the sustained force was 7.6% lower for pushing the high-inertia cart as compared to pushing on MBP treadmill. The differences were not statistically significant. In their 2010 study, Ciriello et al. found that the maximum acceptable initial and sustained forces for pushing the high inertia pushcart were 0.8% and 2.5% lower than those determined using the MPB treadmill; the differences were not statistically significant. Thus, it appears that for females the maximum acceptable pushing and pulling forces determined on a MBP treadmill are applicable to pushing and pulling carts.

For males, Ciriello et al. (1999) reported that the maximum acceptable initial and sustained pushing forces determined using the high-inertia cart were significantly higher, 28% and 23% respectively, than the forces determined using the MPB treadmill. Similarly, their 2010 investigation on male workers Ciriello et al., found that the initial and sustained pushing forces using the high-inertia cart were 18% and 21% higher as compared to those measured on a MPB treadmill. It is not clear why the use of high-inertia cart resulted in higher pushing forces for males but not for females.

4.2. Secular changes in maximum acceptable pushing and pulling forces

Guidelines for maximum acceptable pushing and pulling forces were developed by integrating studies conducted over a 21-year span and published in 1991. One concern is that the physical capabilities of male and female industrial populations may have changed since the data were published in 1991. Four different studies (Ciriello, 2001; Ciriello et al., 1999, 2007, 2008) have reported that the maximum acceptable forces for pushing and pulling were lower for male workers as compared to those reported in 1991. For male workers, Ciriello et al. (1999) and Ciriello (2001) reported that the maximum acceptable initial and sustained forces were 85% and 82% of those reported in 1991 for pushing and 91% and 81% for pulling. Similarly, Ciriello et al. (2007) reported that the maximum acceptable initial and sustained pushing forces for male workers were 82% and 79% of those reported in 1991. Ciriello et al. (2008) reported that the maximum acceptable initial and sustained pushing forces for male workers, on average, were 99% and 86%, respectively. For pulling these forces were 89% and 79% of those reported in 1991. For females, Ciriello (2005) reported that the maximum acceptable initial and sustained forces were higher than those reported in 1991; 107% and 110% of those reported for pushing and 103% and 101% for pulling. A subsequent study (Ciriello et al., 2010) showed that the maximum acceptable sustained force of the MPB treadmill task was 0.5% higher than that reported by Snook and Ciriello (1991). From the above discussion, one could conclude that there has been a decrease in maximum acceptable pushing and pulling forces for males and an increase in these forces for females. However, it is unclear why the reported maximum acceptable forces have changed over time and why the trends are different for males and females. Further, it should be noted that the recent studies are based upon smaller sample sizes than the original study reported in 1991.

4.3. Combined effect of cart and secular changes on Snook and Ciriello (1991) recommendations

From the above discussions it appears that pushing/pulling on a cart versus on a treadmill has little effect on maximum pushing and pulling forces acceptable to females. Further, there has been practically no change in pushing and pulling physical capabilities of females since those data were published in 1991. Overall, the 1991 guidelines still provide an accurate estimate of maximum acceptable forces for the selected combinations of distance and frequency of push/pull for female industrial workers (Ciriello et al., 2010).

For male workers, data suggest that maximum acceptable forces for pushing and pulling a cart are significantly higher (21%) than those determined using the MPB treadmill. This would suggest that an adjustment to maximum acceptable pushing and pulling forces published in 1991 is needed. However, this increase in maximum acceptable forces is countered by a comparable decrease (18%) in male pushing and pulling physical capability on treadmill due to secular changes (Ciriello et al., 2007). It is concluded that the maximum acceptable forces for pushing and pulling published in 1991 still provide an accurate estimate of male pushing and pulling capabilities.

4.4. Pushing and pulling recommendations based on 1991 data

The 1991 publication provided the most comprehensive guidelines for the maximum acceptable two-handed pushing and pulling forces by revising the maximum acceptable initial and sustained pushing and pulling forces published earlier (Snook, 1978) and by integrating results from four new experiments (Ciriello and Snook, 1983; Ciriello et al., 1990) with those from previous experiments (Snook, 1978). The 1991 recommendations are based upon criterion tasks and variation tasks. All subjects (63 males and 51 females for pushing and 53 males and 39 females for pulling) performed the criterion tasks (pushing distance of 7.6 m, handle height = 95 cm for males and 89 cm for females, and frequency = 1/min. for pushing; pulling distance of 2.1 m, handle height = 95 cm for males and 89 cm for females, and frequency = 1/min for pulling tasks). The remaining combinations of height, frequency and distance were classified as variation tasks. The percentage difference from the criterion task was used to develop an adjusted means for variation tasks performed by a small subgroup of the study subjects to examine the effects of frequency, handle height, and distance. Criterion task coefficient of variation and adjusted means for variation tasks were used to determine maximum pushing and pulling forces acceptable to 10%, 25%, 50%, 75%, and 90% of male and female industrial populations. Variations in frequency and distance for pulling are based upon adjustments developed for pushing tasks. Some values reported in tables exceed physiological criteria (HR and/or VO_2) recommended by NIOSH (1981). These maximum acceptable forces are available for (i) males and females, (ii) three different handle heights (64, 95, and 144 cm for males and 57, 89, 135 cm for females), (iii) six pushing/pulling distances (2.1, 7.6, 15.2, 30.5, 45.7 and 61.0 m) and (iv) seven different pushing/pulling frequencies (once every 6 s, 12 s, 1 m, 2 m, 5 m, 30 m, and 8 h.). It should be noted that data are available only for certain combinations of frequency and distance probably because some combinations are not feasible, for example one exertion every 6 and 12 s for distance greater than 2.1 m is not practically feasible. A review of these data leads to the following observations:

1. Gender has a significant effect on both the initial and sustained pushing and pulling forces. In general, the maximum acceptable pushing or pulling forces were lower for females relative to males.
2. Both initial and sustained pushing and pulling forces for both males and females decrease significantly with an increase in pushing/pulling frequency.
3. Both initial and sustained pushing and pulling forces for both males and females decrease significantly with an increase in pushing/pulling distance.
4. Handle height does not appear to have a profound effect on pushing and pulling initial and sustained forces. For pushing optimum height for males is 95 cm and for females 135 cm, both for initial and sustained forces. For males, the optimum height for pulling is 64 cm both for initial and sustained forces. For females, the optimum heights for pulling are 57 cm for initial force and 135 cm for sustained force. The worst heights for males are 64 cm for pushing and 144 cm for pulling. The worst height for females is 57 cm for pushing.
5. In general, maximum acceptable pushing forces were a little higher than those for pulling.

The above observations are consistent with those of Shoaf et al. (1997), who analyzed the effects of these parameters on the initial and sustained maximum acceptable forces.

4.5. Regression equations for maximum acceptable forces

Use of maximum acceptable forces data reported by Snook and Ciriello (1991) requires either approximation or interpolation when job physical exposure variables (handle height, frequency of exertion and/or distance of pushing/pulling) are different than those provided in their tables. We developed regression equations as a function of handle height, pushing/pulling distance and frequency of exertion for initial and sustained pushing and pulling forces acceptable to 75% female and 75% male workers. These regression equations were developed using pushing and pulling data reported by Snook and Ciriello (1991). We selected only forces acceptable to 75% of females and males because it is often recommended that the jobs should be designed to accommodate at least 75% of workers (Snook, 1978; NIOSH, 1981; Waters et al., 1993). These equations might also be useful in the future for comparing psychophysically determined maximum acceptable pushing and pulling forces with the recommendations based upon biomechanical and physiological criteria where handle height, frequency and/or distance are different than those utilized by Snook and Ciriello (1991).

To develop these regression equations we stratified maximum forces acceptable to 75% of workers by type of task (pushing v. pulling), type of force (initial v. sustained) and by gender (female v. male). We then plotted maximum acceptable forces against (i) frequency of exertion, (ii) distance of pushing or pulling and (iii) handle height for pushing or pulling while blocking two of the three independent variables. For example, we plotted initial maximum pushing force acceptable to 75% females against frequency of exertion for each unique combination of distance and handle height. A visual inspection of these graphs showed the following relationships between maximum acceptable forces and the three independent variables (frequency of exertion, distance and handle height):

1. Both initial and sustained pushing and pulling forces showed a logarithmic relationship with frequency of exertion. Subsequent plots of natural log transformations of frequency of exertion showed quadratic relationships with initial pushing and pulling forces both for females and males. Similarly, plots for sustained pushing and pulling forces showed interactions with distance of pushing and pulling.

2. Plots of initial and sustained pushing and pulling forces against distance of pushing or pulling showed logarithmic relationships. The only exception was the plots for initial pulling forces for males showed nearly linear relationships with pulling distance.

3. Plots of initial pushing forces and sustained pushing and pulling forces both for males and females showed quadratic relationships with handle height. However, initial pulling forces both for males and females showed linear relationships with handle height.

Using the above-described relationships, frequency of exertion, distance and handle height were transformed. Separate multiple linear regression equations were fitted for each combination of gender (male or female), task (pushing or pulling), and type of force (initial or sustained). The resulting equations are given below and the correlation coefficients (r^2) and residual standard errors (S.E.) are provided in Table 1. These equations are valid for frequency of exertion ranging from one push/pull every 8 h to one push/pull every 6 s, pushing/pulling distances ranging from 2.1 m to 61 m, and handle height ranging from 57 cm to 135 cm for females and 64 cm–144 cm for males. It should be noted that while these regression equations would provide a value for maximum acceptable pushing or pulling force, some combinations of distance and frequency might not be feasible. For example, a frequency of one push/pull every 6-s is not feasible for a distance of 61 m. When designing new pushing or pulling tasks, it is strongly recommended that users of these equations refer to Snook and Ciriello (1991) tables for guidance in determining feasible combinations of frequency and distance.

Initial Push Force Acceptable to 75% of Female Workers:

$$F=7.360-1{:}405*\ln(E)-0.0947*\ln(E)^2-2.031*\ln(D)+0.287*H-0.00129*H^2 \quad (1)$$

Sustained Push Force Acceptable to 75% of Female Workers:

$$F=9.519-1.382*\ln(E)*D^{-0.215}-1.873*\ln(D)+0.0867*H-0.000389*H^2 \quad (2)$$

Initial Pull Force Acceptable to 75% of Female Workers:

$$F=25.340-1.753*\ln(E)-0.136*\ln(E)^2-2.418*\ln(D)-0.0207*H \quad (3)$$

Sustained Pull Force Acceptable to 75% of Female Workers:

$$F=10.517-1.358*\ln(E)*D^{-0.190}-1.785*\ln(D)+0.0592*H-0.000228*H^2 \quad (4)$$

Initial Push Force Acceptable to 75% of Male Workers:

$$F=11.617-1.938*\ln(E)-0.0678*\ln(E)^2-4.457*\ln(D)+0.484*H-0.00228*H^2 \quad (5)$$

Sustained Push Force Acceptable to 75% of Male Workers:

$$F=19.816-2.059*\ln(E)*D^{-0.135}-3.241*\ln(D)+0.0514*H-0.000225*H^2 \quad (6)$$

Initial Pull Force Acceptable to 75% of Male Workers:

$$F=40.056-1.856*\ln(E)-0.0629*\ln(E)^2-0.216*D-0.132*H \quad (7)$$

Sustained Pull Force Acceptable to 75% of Male Workers:

$$F=21.741-1.932*\ln(E)*D^{-0.130}-2.928*\ln(D)+0.0569*H-0.000572*H^2 \quad (8)$$

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)

H = Handle height (cm)

Correlation coefficients and standard errors for the above regression equations are provided in Table 1. These equations have complex forms due to the following reasons. First, data show nonlinear relationships between distance and maximum acceptable pushing/pulling force, and frequency and maximum acceptable pushing/pulling force. Second, data show that there is an interaction between distance and frequency, and this interaction appears to be more pronounced for sustained pushing/pulling maximum acceptable forces. Further, the relationships between maximum acceptable pushing/pulling forces and height, frequency, and distance appear to be different for: (i) initial versus sustained forces, and (ii) pushing versus pulling. Last, there are a few inconsistencies in the data reported in Snook and Ciriello (1991) that make it difficult to fit regression equations while minimizing standard error. For example, while in general the maximum acceptable initial pushing forces acceptable to 75% of females show a non-linear decrease with an increase in distance, the data are identical for both 30.5 m and 45.7 m pushing distances.

4.6. Physiological assessments

A few studies have assessed oxygen uptake (VO_2) and/or heart rate (HR) for psychophysically determined maximum acceptable pushing and pulling forces (Ciriello and Snook, 1983; Snook and Ciriello, 1991; Ciriello et al., 1993; Dempsey et al., 2008). These studies showed that the HR and VO_2 might be too high for certain combinations of pushing distances and frequencies. Snook and Ciriello (1991) identified combinations of distance, frequency and handle height of pushing/pulling tasks that exceeded 8-h physiological criteria (0.7 l/min for females, 1.0 l/min for males). These combinations for sustained pushing and pulling forces are summarized in Table 2. In general the physiological criteria are exceeded at relatively higher frequency of exertion for a given distance (e.g. one exertion every 6 or 12 s for 2.1 m push, one exertion every 1–2 min for 45.7 m push). When pushing/pulling a cart, oxygen uptake is affected by, among other variables, magnitude of pushing/pulling force, body posture, frequency of pushing/pulling, velocity, and gender (van der Beek et al., 2000; Dempsey et al., 2008). At present, unlike lifting and lowering tasks, the relationships between oxygen uptake and pushing/pulling force, velocity, frequency, distance and body posture, etc. are not well defined. Therefore, it is not clear how much reduction in maximum acceptable pushing/pulling forces is needed to satisfy physiological criteria. It is suggested that caution should be used when using maximum acceptable pushing/pulling forces for combinations of distance and frequency identified in Table 2.

5. Discussions

Most of the scientific studies on pushing and pulling have utilized psychophysics, either maximum isometric or isokinetic pushing and pulling strengths for a single exertion or maximum acceptable pushing and pulling forces for repetitive pushing and pulling. Between these two types of data, maximum acceptable forces provide the most comprehensive data for recommending acceptable levels of pushing and pulling forces for designing and analyzing pushing/pulling tasks in industry as these data reflect the effects of handle height, frequency of exertion and pushing/pulling distance. It is believed that the Snook and Ciriello (1991) pushing and pulling recommendations are still valid both for males and females when one accounts for differences in pushing and pulling forces measured against a cart versus a handle bar on a treadmill and secular changes in pushing/pulling forces measured since 1991. Therefore, at present it appears that adjustments to the 1991 guidelines are not necessary until additional data confirm that the male and female physical capabilities for pushing are lower than those reported in 1991 (Ciriello et al., 2008, 2010). Therefore, we fitted regression equations to the 1991 data to estimate initial and sustained pushing and pulling forces as a function of height, frequency of pushing/pulling and pushing/pulling/ distance acceptable to 75% female and 75% male workers. We believe these equations would be useful to practitioners and employers when designing and analyzing pushing/ pulling tasks that are common in industry.

Regarding maximum acceptable pushing and pulling forces, the assumption in psychophysics is that an individual can determine his or her maximum pushing and pulling initial and sustained forces that would not lead to an adverse health outcome. In this regard, two different studies (Snook, 1978; Herrin et al., 1986) have shown that if manual materials handling tasks are designed using psychophysical data to accommodate a certain percentage of population (Snook et al. 75% and Herrin et al. 90%) low-back and musculoskeletal injuries can be reduced. However, there are no studies reported in the scientific literature that have exclusively studied associations between maximum acceptable pushing and pulling forces and risk of musculoskeletal injuries. Further, the relationship between the exerted pushing and pulling forces and low back and shoulder disorders has been rarely studied. There is evidence to suggest that in certain combinations of pushing/pulling force, frequency, distance and height etc. would lead to low back pain and shoulder injuries (Frymoyer et al., 1980; NIOSH, 1981; Damkot et al., 1984; Klein et al., 1984; Metzler, 1985; Harber et al., 1987; Pope, 1989; Lee et al., 1992; Garg and Moore, 1992; Meyers et al., 1993; van der Beek et al., 1993; Hoozemans et al., 2002a,b; Harkness et al., 2003). What is not clear is what these combinations are. It is recognized that these studies, while definitely needed, might be difficult to perform, as most tasks in industry require a combination of lifting/lowering and pushing/pulling, and it might be difficult to separate the causation (lifting/lowering v. pushing/pulling) in certain cases. Well designed studies that include tasks with either no or low exposure to lifting but both low and high exposure to pushing/pulling forces may be able to establish associations between psychophysically determined maximum acceptable forces and risk of musculoskeletal injuries, particularly low-back and shoulder disorders.

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 have quantified stresses to both low back and shoulder joints from pushing and pulling of loads (Schibye et al., 2001; de Looze et al., 2000; Hoozemans et al., 2004). Ideally, the recommendations on cart design such as handle height and maximum allowable pushing and pulling forces should consider minimizing stresses to both shoulder joints as well as low back. It is clear from these studies that the combination of force direction (pushing v. pulling), force magnitude, body posture and height affects shoulder moments and compressive and shear forces to low back. What is not clear is that what combinations of these variables subject a worker to an increased risk of low back and/or shoulder injuries. For example, for pulling tasks, Lett and McGill (2006) recommended waist height over shoulder height to minimize compressive and shear forces on low back. On the other hand, Hoozemans et al. (1998, 2004) recommended that carts should be designed and used to push or pull at shoulder height to minimize moments at the shoulder by keeping the wrist, elbow and shoulder close to the line of action of the exerted force. It is believed that the psychophysically determined maximum acceptable pushing and pulling forces provide practical recommendations for job design and risk assessment until more comprehensive biomechanical data become available and the differences in recommendations from the two disciplines can be evaluated.

Another concern regarding psychophysically determined maximum acceptable pushing and pulling forces is that the sustained pushing and/or pulling forces for certain combinations of frequency, distance and height may cause excessive physical fatigue. Snook and Ciriello (1991) identified these combinations (see Table 2). Therefore, sustained maximum acceptable pushing and pulling forces for these combinations need to be reduced. At present it is unclear how much reduction in these forces is required to keep them within physiological limits. It is recommended that practitioners should use caution when using these combinations of height, frequency and distance.

A second concern with psychophysically determined maximum acceptable pushing and pulling forces is that initial maximum forces for low frequency pushing and pulling tasks may be difficult to determine using the adjustment methodology employed for psychophysical studies. Since the methodology relies on the subjects’ ability to increase or decrease the forces between various pushes and pulls, it is unclear how the subject can accurately adjust the forces for very infrequent activities, such as those performed only a few times per day. Therefore, it is suggested that biomechanical limits should also be considered when designing or evaluating very infrequent pushes and pulls.

Psychophysically determined forces are a little higher for pushing than for pulling, implying that pushing is preferable over pulling. However, biomechanical evidence of an advantage between pushing and pulling is inconclusive (Lee et al., 1991; Hoozemans et al., 2004; Lett and McGill, 2006; Knapik and Marras, 2009). Therefore, at present it is unclear, given a choice, whether workers should be encouraged to push or pull loads. Another question of interest to practitioners is what the optimum handle height for pushing and pulling of carts should be. At present due to differences in males and females for preferable handle height as well as conflicts within the biomechanical studies for recommended handle heights for pushing and pulling, it is difficult to suggest what the optimum handle heights for pushing and pulling are. This issue becomes even more complex when one considers stresses to both the low back as well as the shoulders. In the absence of clear information, we believe that the psychophysically determined maximum acceptable forces provide useful information for designing and analyzing pushing/pulling tasks, as these reflect an integrated response from the worker. However, additional studies comparing psychophysical maximum acceptable pushing and pulling forces to biomechanical and physiological based limits for pushing and pulling are needed.

6. Conclusions

A comprehensive review of maximum acceptable pushing and pulling forces shows that the 1991 guidelines from Snook and Ciriello for pushing and pulling forces are still valid for pushing and pulling carts. For very low frequency pushing and pulling tasks (e.g. less often than one effort per hour), biomechanical criteria should be considered to confirm that compressive and shear forces produced from maximum acceptable forces do not exceed recommended biomechanical limits. Similarly, these low frequency maximum acceptable pushing and pulling forces should be evaluated to make sure that they do not produce unacceptably high moments and stresses to shoulder joints. For high frequency tasks, physiological criteria may be helpful to determine that maximum acceptable forces are within the workers' physiological limits.

Regression equations fitted to the psychophysical data to estimate initial and sustained forces acceptable to 75% of female and 75% of male workers should be useful to employers and practitioners who design and analyze pushing and pulling tasks in industry. At present it is unclear whether it is preferable to push or pull. Similarly, it is difficult to make recommendations for optimum handle height, as pushing and pulling tasks could be stressful to both the low back and the shoulders. There is a critical need for comprehensive epidemiological studies linking exposure to pushing and pulling tasks and risk of low back pain and/or shoulder disorders. These studies must be well designed and focused on assessing risk associated with pushing and pulling tasks.

References

Abel EW, Frank TG. The design of attended propelled wheelchairs. Prosthet Orthot Int. 1991; 15:38–45. [PubMed: 1857639]

Al-Eisawi KW, Kerk CJ, Gongleton JJ, Amendola AA, Jenkins OC, Gains WG. The effect of handle height and cart load on the initial hand forces in cart pushing and pulling. Ergonomics. 1999a; 42(8):1099–1113.

Al-Eisawi KW, Kerk CJ, Gongleton JJ, Amendola AA, Jenkins OC, Gains WG. Factors affecting minimum push and pull forces of manual carts. Appl Ergon. 1999b; 30(3):235–245. [PubMed: 10327087]

Ayoub MM, McDaniel JW. The effects of operator stance on pushing and pulling tasks. AIIE Trans. 1974; 6:185–195.

Ayoub MM, Mital A, Bakken GM, Asfour SS, Bethea NJ. Development of strength capacity norms for manual materials handling. Hum Factors. 1980; 22:271–283.

Baril-Gingras G, Lortie M. The handling of objects other than boxes: univariate analysis of handling techniques in large transport company. Ergonomics. 1995; 38:905–925.

Boocock MG, Haslam RA, Lemon P, Thorpe S. Initial force and postural adaptations when pushing and pulling on floor surfaces with good and reduced resistance to slipping. Ergonomics. 2006; 49(9):801–821. [PubMed: 16801229]

Borg G. Perceived exertion as an indicator of somatic stress. Scand J Rehabil Med. 1970; 2:92–98. [PubMed: 5523831]

Chaffin DB. Manual materials handling and the biomechanical basis for prevention of low-back pain in industry- an overview. Am Ind Hyg Assoc J. 1987; 48:989–996. [PubMed: 2963515]

Chaffin DB, Andres RO, Garg A. Volitional postures during maximal push/pull exertions in the sagittal plane. Hum Factors. 1983; 25(5):541–550. [PubMed: 6667943]

Chaffin, DB.; Anderson, GBJ.; Martin, BJ. Occupational Biomechanics. third. John Wiley & Sons, Inc; New York: 1999.

Ciriello VM. The effects of box size, vertical distance, and height on lowering tasks. Int J Ind Ergon. 2001; 28(2):61–67.

Ciriello VM. Comparison of two techniques to establish maximum acceptable forces of dynamic pushing for female industrial workers. Int J Ind Ergon. 2004; 34:93–99.

Ciriello VM. Psychophysically determined horizontal and vertical forces of dynamic pushing on high and low coefficient of friction floors for female industrial workers. J Occup Environ Hyg. 2005; 2:136–142. [PubMed: 15764537]

Ciriello VM, Snook S. A study of size, distance, height, and frequency effects on manual handling tasks. Hum Factors. 1983; 25:473–483. [PubMed: 6667937]

Ciriello VM, Snook SH, Blick AC, Wilkinson PL. The effects of task duration on maximum acceptable weights and forces. Ergonomics. 1990; 33:187–200. [PubMed: 2354696]

Ciriello VM, Snook SH, Hughes GJ. Further studies of psychophysically determined maximum acceptable weights and forces. Hum Factors. 1993; 35:175–186. [PubMed: 8509102]

Ciriello VM, McGorry RW, Martin SE, Bezverkhny IB. Maximum acceptable forces of dynamic pushing: comparison of two techniques. Ergonomics. 1999; 42:32–39. [PubMed: 9973870]

Ciriello VM, Snook SH, Hashemi L, Cotnam J. Distributions of materials handling task parameters. Int J Ind Ergon. 1999; 24:379–388.

Ciriello VM, McGorry RW, Martin SE. Maximum acceptable horizontal and vertical forces of dynamic pushing on high and low coefficient of friction floors. Int J Ind Ergon. 2001; 27:1–8.

Ciriello VM, McGorry RW, Martin SE, Bezerkhny IB. Maximum acceptable forces of dynamic pushing: comparison of two techniques. Ergonomics. 2004; 42(1):32–39. [PubMed: 9973870]

Ciriello VM, Maikala RV, Dempsey PG, O'Brien NV. Revisited: comparison of two techniques to establish maximum acceptable forces of dynamic pushing for male industrial workers. Int J Ind Ergon. 2007; 37:877–882.

Ciriello VM, Dempsey PG, Maikala RV, O'Brien NV. Secular changes in psychophysically determined maximum acceptable weights and forces over 20 years for male industrial workers. Ergonomics. 2008; 51(5):593–601. [PubMed: 18432440]

Ciriello VM, Maikala RV, Dempsey PG, O'Brien NV. Psychophysically determined forces of dynamic pushing for female industrial workers: comparison of two apparatuses. Appl Ergon. 2010; 41:141–145. [PubMed: 19628201]

Daams BJ. Static force exertion in postures with different degrees of freedom. Ergonomics. 1993; 36:397–406. [PubMed: 8472687]

Damkot DK, Pope MH, Lord J, Frymoyer JW. The relationship between work history, work environment and low-back pain in men. Spine. 1984; 9:395–399. [PubMed: 6236564]

Das B, Wimpee J, Das B. *Ergonomics* evaluation and redesign of a hospital meal cart. Appl Ergon. 2002; 33(4):309–318. [PubMed: 12160335]

David, GC.; Nicholson, AS. The Safety Practitioner. Institution of Occupational Safety and Health; Leicester, UK: Jul. 1985 Aids to lifting and handling; p. 4-7.

de Looze MP, Stassen ARA, Markslag AMT, Borst MJ, Wooning MM, Toussaint HM. Mechanical loading on the low back in three models of refuse collecting. Ergonomics. 1995; 38:1993–2006. [PubMed: 7588581] de Looze MP, van Greuningen K, Rebel J, Kingma I, Kuijer PPFM. Force direction and physical load in dynamic pushing and pulling. Ergonomics. 2000; 43(3):377–390. [PubMed: 10755660]

Dempsey PG, Ciriello VM, Maikala RV, O'Brien NV. Oxygen consumption prediction models for individual and combination manual materials handling tasks. Ergonomics. 2008; 51:1776–1789. [PubMed: 18941980]

Drury, CG.; Barnes, RE.; Daniels, EB. Pedestrian operated vehicles in hospitals. Proceedings of the 26th Spring Annual Conference and World Productivity Congress; Norcross, GA: American Institute of Industrial Engineers; 1975. p. 184-191.

Eastman Kodak Co. Ergonomic Design for People at Work. Vol. 2. Van Nostrand Reinhold; New York: 1986.

Eisler H. Subjective scale of force for a large muscle group. J Exp Psychol. 1962; 64:253–257. [PubMed: 13889707]

Fothergill DM, Grieve DE, Pheasant ST. Human strength capabilities during on-handed maximum voluntary exertions in the fore and aft plane. Ergonomics. 1991; 34(5):563–573. [PubMed: 1884710]

Fothergill DM, Grieve DE, Pheasant ST. The influence of some handle designs and handle height on the strength of the horizontal pulling action. Ergonomics. 1992; 35(2):203–212.

Frings-Dresen MHW, Kemper HCG, Stassen ARA, Crolla IFAM, Markslag AMT. The daily work load of refuse collectors working with three different collecting methods: a field study. Ergonomics. 1995a; 38:2045–2055.

Frings-Dresen MHW, Kemper HCG, Stassen ARA, Markslag AMT, de Looze MP, Toussaint HM. Guidelines for energetic load in three methods of reuse collecting. Ergonomics. 1995b; 38:2056–2064.

Frymoyer JW, Pope MH, Costanza MC, Rosen JC, Goggin JE, Wilder DG. Epidemiologic studies of low back pain. Spine. 1980; 5:419–423. [PubMed: 6450452]

Garcin M, Cravic JY, Vandewalle H, Monod H. Physiological strains while pushing or hauling. Eur J Appl Physiol. 1996; 72:278–482.

Garg A, Ayoub MM. What criteria exist for determining how much load can be lifted safely? Hum Factors. 1980; 22(4):475–486.

Garg A, Badger D. Maximum acceptable weights and maximum voluntary isometric strengths for asymmetric lifting. Ergonomics. 1986; 29(7):879–892. [PubMed: 3743543]

Garg A, Beller D. One-handed dynamic pulling strength with special reference to speed, handle height and angles of pulling. Int J Ind Ergon. 1990; 6:231–240.

Garg A, Moore J. Epidemiology of low back pain in industry. Occup Med. 1992; 7:593–608. [PubMed: 1411850]

Garg A, Funk S, Janisch D. One-handed dynamic pulling strength with special application to lawn mowers. Ergonomics. 1988; 31(8):1139–1153.

Glitsch U, Ottersbach HJ, Ellegast R, Schaub K, Franz G, Jäger M. Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft. Int J Ind Ergon. 2007; 37(11–12): 845–854.

Granata KP, Bennet BC. Low-back biomechanics and static stability during isometric pushing. Hum Factors. 2005; 47(3):536–549. [PubMed: 16435695]

Grieve DW. Slipping due to manual exertion. Ergonomics. 1983; 25:61–72. [PubMed: 6832134]

Hansson, JE. Ergonomi Och Produktion-steknik, Al-Rapport 2. National Institute of Occupational Health; Stockholm, Sweden: 1968. Work Physiology as a Tool in Ergonomics and Production Engineering.

Harber P, Billet E, Lew M, Horan M. Importance of non-patience transfer activities in nursing-related back pain: I. questionnaire survey. J Occup Med. 1987; 29:967–970. [PubMed: 2963097]

Harkness EF, Macfarlane GJ, Nahit ES, Silman AJ, McBeth J. Mechanical and psychosocial factors predict new onset shoulder pain; a prospective cohort study of newly employed workers. Occup Environ Med. 2003; 6:850–857. [PubMed: 14573715]

Haslam RA, Boocock M, Lemon P, Thorpe S. Maximum acceptable loads for pushing and pulling on floor surfaces with good and reduced resistance to slipping. Safety Sci. 2002; 40(7–8):625–637.

Herrin GD, Jaraiedi M, Anderson CK. Prediction of overexertion injuries using biomechanical and psychophysical models. AIHA Journal. 1986; 47(6):322–330. [PubMed: 2943150]

Herring S, Hallbeck MS. The effects of distance and height on maximal isometric push and pull strength with reference to manual transmission truck drivers. Int J Ind Ergon. 2007; 37(8):685–696.

Hoozemans MJ, Van Der Beek AJ, Frings-Dresen MH, Van Dijk FJ, Van Der Woude LH. Pushing and pulling in relation to musculoskeletal disorders: a review of risk factors. Ergonomics. 1998; 41:757–781. [PubMed: 9629062]

Hoozemans MJM, van der Beek AJ, Frings-Dresen MHW, van der Molen HF. Evaluation of methods to assess push/pull forces in a construction task. Appl Ergon. 2001; 32(5):509–516. [PubMed: 11534796]

Hoozemans MJ, van der Beek AJ, Frings-Dresen MH, van der Woude, van Dijk FJH. Low-back and shoulder complaints among workers with pushing and pulling tasks. Scand J Work Environ Health. 2002a; 28:293–303. [PubMed: 12432982]

Hoozemans MJM, van der Beek AJ, Frings-Dresen MHW, van der Woude LHV, van Dijk FJH. Pushing and pulling in association with low back and shoulder complaints. Occup Environ Med. 2002b; 59:696–702. [PubMed: 12356931]

Hoozemans MJM, Kuijer PPFM, Knigma I, van Dieen JH, de Vries WHD, van der Woude LHV, Veeger DJ, van deer Beek AJ, Frings-Dresen MHW. Mechanical loading of the low back and shoulders during pushing and pulling activities. Ergonomics. 2004; 47(1):1–18. [PubMed: 14660215]

Jäger M, Luttmann A, Larig W. The load on the spine during the transport of dustbins. Appl Ergon. 1984; 15(2):91–98. [PubMed: 15676505]

Jansen JP, Hoozemans MJM, van der Beek AJ, Frings-Dresen MHW. Evaluation of ergonomic adjustments of catering carts to reduce external pushing forces. Appl Ergon. 2002; 33:117–127. [PubMed: 12009118]

Jung M, Haight JM, Freivalds A. Pushing and pulling carts and two-wheeled hand trucks. Int J Ind Ergon. 2005; 35:79–89.

Karwowski W, Ayoub MM. Fuzzy modeling of stresses in manual lifting tasks. Ergonomics. 1984; 27(6):641–649. [PubMed: 6479142]

Karwowski, W.; Gaddie, PR. Simulation of the 1991 revised NIOSH manual lifting equation. Proceedings of the Human Factors and Ergonomics Society Annual Meeting; Santa Monica, CA. 1995. p. 699-701.

Karwowski, W.; Pongpatana, N. The effect of color on human perception of load heaviness. In: Mital, IA., editor. Advances in Industrial Ergonomics and Safety. Taylor & Francis; London: 1989. p. 673-678.

Karwowski W, Lee WG, Jamaldin B, Gaddie P, Jang R. Beyond psycho-physics: a need for cognitive modeling approach to setting limits in manual lifting tasks. Ergonomics. 1999; 42(1):40–60. [PubMed: 9973871]

Keyserling WM, Herrin GD, Chaffin DB. Isometric strength testing as a means of controlling medical incidents on strenuous jobs. J Occup Med. 1980; 22:332–336. [PubMed: 7381613]

Kingma I, Kuijer PPFM, Hoozemans MJM, van Dieen JH, van der Beek AJ, Frings-Dresen MHW. Effect of design of two-wheeled containers on mechanical loading. Int J Ind Ergon. 2003; 31:73–86.

Klein BP, Jensen RJ, Sanderson LM. Assessment of workers' compensation claims for back strains/sprains. J Occup Med. 1984; 26:443–448. [PubMed: 6234383]

Knapik GG, Marras WS. Spine loading at different lumbar levels during pushing and pulling. Ergonomics. 2009; 52(1):60–70. [PubMed: 19308819]

Konz, S.; Johnson, S. Work Design: Industrial Ergonomics. sixth. Holcomb Hathaway; Arizona: 2004.

Kuijer PPFM, Hoozemansb MJM, Frings-Dresen MHW. A different approach for the ergonomic evaluation of pushing and pulling in practice. Int J Ind Ergon. 2007; 37:855–862.

Kumar S. Upper body push-pull strength of normal young adults in sagittal plane at three heights. J Ind Ergon. 1995; 15:427–436.

Kumar S, Narayan Y, Bacchus C. Symmetric and asymmetric two-handed pull-push strength of young adults. Hum Factors. 1995; 37(4):854–865. [PubMed: 8851781]

Laursen B, Schibye B. The effect of different surfaces on biomechanical loading of shoulder and lumbar spine during pushing and pulling of two-wheeled containers. Appl Ergon. 2002; 33:167–174. [PubMed: 12009123]

Lawson J, Potiki J, Watson H. Development of ergonomics guidelines for manually handled trolleys in the health industry. J Occup Health Saf Aust New Zeal. 1993; 9(5):459–465.

Lee T. Pushing strength under restricted space. Hum Factors Ergon Manuf. 2007; 17(1):95–102.

Lee KS, Chaffin DB, Herrin GD, Waikar AM. Effect of handle height on lower back loading in cart pushing and pulling. Appl Ergon. 1991; 22(2):117–123. [PubMed: 15676806]

Lee KS, Chaffin DB, Parks C. A study of slip potential during cart pushing and pulling. IIE Trans. 1992; 24(5):139–146.

Lett KK, McGill S. Pushing and pulling: personal mechanics influence spine loads. Ergonomics. 2006; 49(9):895–908. [PubMed: 16801235]

Mack K, Haslegrave CM, Gray MI. Usability of manual handling aids for transporting materials. Appl Ergon. 1995; 26:353–364. [PubMed: 15677037]

Maikala RV, Dempsey PG, Ciriello VM, O'Brien NV. Dynamic pushing on three frictional surfaces: maximum acceptable forces, cardiopulmonary and calf muscle metabolic responses in healthy men. Ergonomics. 2009; 52:735–746. [PubMed: 19431004]

Marras, W.; Karwowski, W. The Occupational Ergonomics Handbook. CRC Press; Boca Raton, FL: 1999.

Marras WS, Knapik GG, Ferguson S. Lumbar spine forces during maneuvering of ceiling-based and floor-based patient transfer devices. Ergonomics. 2009; 52:384–397. [PubMed: 19296324]

McGill, S. Low Back Disorders: Evidence-based Prevention and Rehabilitation. Human Kinetics; Champaign, IL: 2002.

Metzler F. Epidemiology and statistics in Luxumbourg. Am Ind Hyg Assoc J. 1985; 28:21–24.

Meyers A, Jensen RC, Nestor D, Rattiner J. Low back injuries among home health aides compared with hospital nursing aides. Home Health Care Serv Q. 1993; 14(2/3):149–155. [PubMed: 10133713]

Miller, J. The ergonomics of in-flight service on aircraft in Australian domestic airlines. Proceedings of the 22nd Annual Conference of the Ergonomics Society of Australia and New Zealand; Australia. 1985. p. 45-52.

Mital A. Comprehensive maximum acceptable weight of lift database for regular 8-hour workshifts. Ergonomics. 1984; 27:1127–1138. [PubMed: 6519052]

National Institute for Occupational Safety and Health (NIOSH). Work Practices Guide for Manual Lifting. Cincinaati, Ohio: 1981. Technical Report No. 81-122

Pope MH. Risk indicators in low back pain. Ann Med. 1989; 21:387–392. [PubMed: 2532529]

Resnick ML, Chaffin DB. An ergonomic evaluation of handle height and load in maximal and submaximal cart pushing. Appl Ergon. 1995; 26(3):173–178. [PubMed: 15677015]

Resnick ML, Chaffin DB. Kinematics, kinetics, and psychophysical perceptions in symmetric and twisting pushing and pulling tasks. Hum Factors. 1996; 38(1):114–129. [PubMed: 8682516]

Ridyard DT. Effectiveness of ergonomics controls in a chemical plant. Adv Ind Ergon Saf. 1990; II: 125–129.

Schibye B, Søgaard K, Martinsen D, Klausen K. Mechanical load on the low back and shoulders during pushing and pulling of two-wheeled waste containers compared with lifting and carrying of bags and bins. Clin Biomech. 2001; 16(7):549–559.

Shoaf C, Genaidy A, Karwowski W, Waters T, Christensen D. Comprehensive manual handling limits for lowering, pushing, pulling and carrying activities. Ergonomics. 1997; 40(11):1183–1200. [PubMed: 9375533]

Snook SH. The design of manual handling tasks. Ergonomics. 1978; 21:963–985. [PubMed: 729559]

Snook SJ, Ciriello VM. Maximum weights and work loads acceptable to female workers. J Occup Med. 1974a; 16(8):527–534. [PubMed: 4843402]

Snook SJ, Ciriello VM. The effects of heat stress on manual handling tasks. AIHA Journal. 1974b; 35(11):681–685. [PubMed: 4429074]

Snook SH, Ciriello VM. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics. 1991; 34:1197–1213. [PubMed: 1743178]

Snook SH, Irvine CH. Psychophysical studies of physiological fatigue criteria. Hum Factors. 1969; 11(3):291–300. [PubMed: 4389068]

Snook SH, Irvine CH, Bass SF. Maximum weights and work loads acceptable to male industrial workers. AIHA Journal. 1970; 31(5):579–586. [PubMed: 5488305]

Stevens SS. The psychophysics of sensory function. Am Sci. 1960; 48:226–253.

van der Beek AJ, Frings-Dresen MHW, van Dijk FJH, Kemper HCG, Meijman TF. Loading and unloading by lorry drivers and musculoskeletal complaints. Int J Ind Ergon. 1993; 12:13–23.

van der Beek AJ, Hoozemans MJM, Fring-Dresen MHW, Burdoff A. Assessment of exposure to pushing and pulling in epidemiological field studies: an overview of methods, exposure measures, and measurement strategies. Int J Ind Ergon. 1999; 24:417–429.

van der Beek AJ, Kluver BDR, Frings-Dresen MHW, Hoozemans MJM. Gender differences in exerted forces and physiological load during pushing and pulling of wheeled cages by postal workers. Ergonomics. 2000; 43(2):269–281. [PubMed: 10675063]

van der Woude LHV, van Konings Bruggen CM, Kroes AL, Kingma I. Effect of handle height on net moments and forces on the musculoskeletal system during standardized wheelchair pushing tasks. Prosthet Orthot Int. 1995; 19:188–201. [PubMed: 8927531]

Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH lifting equation for design and evaluation of manual lifting tasks. Ergonomics. 1993; 36:749–776. [PubMed: 8339717]

Winkel J. On the manual handling of wide-body carts used by cabin attendants in civil aircraft. Appl Ergon. 1983; 14:162–168. [PubMed: 15676476]

Wissenden, J.; Evans, O. Can the standard horizontal trolley handle be improved?. Proceedings of the 36th Annual Conference of the Ergonomics Society of Australia; Australia: Ergonomics Society of Australia; 2000. p. 84-89.

Zurada J, Karwowski W, Marras WS. Classification of jobs with risk of low back disorders by applying data mining techniques. Occup Ergon. 2004; 4(4):291–305.

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Relevance to industry

This article provides a concise discussion of important factors relevant to designing and analyzing pushing/pulling tasks. Regression equations to estimate initial and sustained pushing and pulling forces acceptable to 75% male and female workers are provided and can be used to design and analyze pushing and pulling tasks common in industry.

Table 1

Correlation coefficients and standard errors for regression equations fitted to Snook and Ciriello (1991) maximum acceptable push and pull force data.

Task	Type of force	Gender	Eq. #	r^2	S.E.
Push	Initial	Female	1	0.93	0.90
Push	Sustained	Female	2	0.92	0.87
Pull	Initial	Female	3	0.93	0.95
Pull	Sustained	Female	4	0.92	0.90
Push	Initial	Male	5	0.91	1.95
Push	Sustained	Male	6	0.94	1.30
Pull	Initial	Male	7	0.92	1.93
Pull	Sustained	Male	8	0.93	1.45

Table 2

Combinations of distance and frequency for maximum acceptable sustained push/pull forces (Snook and Ciriello, 1991) acceptable to 75% of workers that exceed 8-h physiological criteria (0.7 l/min for females and 1.0 l/min for males).

Gender	Distance (m)	Frequency (1 exertion every)	
		Push	Pull
Females	2.1	6 s, 12 s	6 s, 12 s
Females	7.6	15 s, 22 s	15 s, 22 s
Females	15.2	25 s, 35 s, 1 m	25 s, 35 s, 1 m
Females	30.5	1 m, 2 m	1 m, 2 m
Females	45.7	1 m, 2 m	1 m, 2 m
Females	61.0	2 m	2 m
Males	2.1	6 s	6 s[a]
Males	7.6	15 s, 22 s	15 s, 22 s[a]
Males	15.2	25 s, 35 s	25 s, 35 s, 1 m[b]
Males	30.5	1 m	1 m
Males	45.7	1 m, 2 m	1 m, 2 m[a]
Males	61.0	2 m	2 m[a]

[a] Exceeds 8-h physiological criteria (1.0 l/min for males) for 64 and 95 cm handle heights.

[b] Exceeds 8-h physiological criteria (1.0 l/min for males) for 64 cm handle height only.