CURRENT TRENDS IN RESEARCH FOCUSED ON PUSHING AND PULLING

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ABSTRACT

The purpose of this review paper is to provide a synopsis of the findings of papers on pushing and pulling; and to identify areas of contention which require further in depth analysis. It is evident from reviewing the published papers on pushing and pulling that there is a lack of consensus as to which one of these two actions has the greatest force production. The main problem is probably the lack of standardized methodology in push-pull research. Furthermore, even when similar methodologies have been used the description of postures adopted during testing by the subjects varies greatly from paper to paper. The various studies have employed different postures and also imposed different restrictions on the postures adopted during experimentation, making comparisons between findings difficult. Much emphasis has been placed on the evaluation of static pushing and pulling tasks, and there is a clear need for further research into dynamic pushing and pulling. Additionally to date the focus of much of this research has been on the biomechanical stresses placed on the body with little attention being given to the physiological cost of pushing and pulling.

INTRODUCTION

Even though manual materials handling (MMH) has been the focus of much attention amongst ergonomics researchers for well over 30 years (Buckle *et al.,* 1992; Ayoub, 1999; Mital and Ramakrishnan, 1999), it remains a major source of loss in industry, representing approximately 30 % of direct costs in the United States and the United Kingdom (Dempsey, 2003). Despite the attention that has been given to ergonomics in both industrialized and developing countries, the occurrence of musculoskeletal complaints in the workplace are still a considerable problem (Westgaard and Winkel, 1997; Marras, 2000). Recently Mital and Ramakrishnan (1999) argued that despite the efforts to contain the hazards of MMH, the number, severity and cost of injuries has either remained unchanged or continued to grow. Historically MMH has generally been achieved through the lifting and carrying of objects, hence most of the research into MMH has focused on the demands of lifting. The very nature of these manual tasks predisposes workers to high levels of physical stress, which manifest themselves as strains on the musculoskeletal and cardiovascular systems. When these physical stressors exceed the physical capabilities of the human operator, it is likely to lead to a high risk of discomfort, fatigue and ultimately injury.

The high costs and hazards associated with repetitive lifting MMH have been well documented (Resnick and Chaffin, 1995). Al-Eisawi *et al.* (1999) and Schibye *et al.* (2001) argued that as a result job designers have attempted to eliminate these tasks from the job profile with the introduction of carts and other manual materials handling devices such as mechanical arms and hoists. Svedberg (1987) and Hoozemans *et al.* (2001) argued that many heavy work operations have been completely or partially replaced as improved methods of working and more sophisticated technology has been instituted.

PUSHING AND PULLING

The use of industrial carts has meant that the lifting component of MMH has been replaced by repetitive pushing and pulling tasks (Resnick and Chaffin, 1995; Al-Eisawi *et al.,* 1999; Laursen and Schibye, 2002; Kingma *et al.,* 2003; Ciriello, 2004). Consequently over the last two decades there has been a substantial increase in the amount of pushing and pulling seen in industry. Kumar (1995) and Jansen *et al.* (2002) report that pushing and pulling now account for as much as 50% of all manual materials handling tasks.

The attraction of the implementation of carts is that a well-designed cart can be used to move heavy loads with forces that are acceptable to the majority of the workforce, thereby reducing the demands on the musculoskeletal system of the operator (Ciriello, 2004). Straker *et al.* (1996) found the physical limits for pushing and pulling to be more than double the limits for lifting, lowering and carrying, as well as being subjectively rated as being less strenuous than lifting. However, Svedberg (1987) and Resnick and Chaffin (1995) caution that although advances in technology have reduced the number of lifting tasks prevalent in industry, these changes themselves cause a myriad of fresh demands to be placed on the human operator. Resnick and Chaffin (1995) argued that these changes are going to fundamentally change the ergonomic stresses of such jobs, and may not necessarily reduce the overall musculoskeletal strain that is associated with the completion of the task (Woldstad and Chaffin, 1994).

Even with the increased prevalence of pushing and pulling as a form of manual work, and the recent documentation of the high associated injury costs, Jansen *et al.* (2002) argued that MMH tasks involving pushing and pulling have received limited scientific attention. Lee *et al.* (1989) contend that little research has focused on the prediction of forces in the lower back during pushing and pulling. Recently Laursen and Schibye (2002) found that the biomechanical load during pushing and pulling had received scant attention when compared to the biomechanical load involved in lifting tasks. It is evident that there has not been sufficient scientific research into pushing and pulling tasks in order to be able to identify the associated factors which are likely to lead to musculoskeletal injuries, and increase the likelihood of slip, trip and fall accidents.

Epidemiology

Berndsen (1990), Nilsson and Dahlman (1994) and Woldstad and Chaffin (1994) have all argued that manual materials handling devices do not necessarily reduce the overall musculoskeletal strain experienced by workers completing the task. Al-Eisawi *et al.* (1999) and Hoozemans *et al.* (2004) found that pushing and pulling tasks account for as much as 20% of all injury claims in the United States. Kingma et al. (2003) argued that 9-20% of the cases of lower back injuries are the direct result of pushing and pulling. Van der Beek *et al.* (1993) and Hoozemans *et al. (*1998) found that pushing and pulling led to an increase in the incidence of pain and stiffness in the neck and shoulder regions. Furthermore, with the incidence of pushing and pulling in industry on the increase, it could be expected that the percentage of total musculoskeletal problems associated with manual work being caused by pushing and pulling will also become increasingly evident. In order to reduce the risk of musculoskeletal complaints related to pushing and pulling, these tasks need to be designed to minimise the short and long term health risk to the workers.

The epidemiology studies to date have focused on the injury complaints and rates in industrially developed countries (IACs) such as the United States and the countries comprising the European Union. In industrially developing countries (IDCs) the lack of automation necessitates the increased prevalence of manual materials handling tasks. It could therefore be extrapolated that the injury rates, and consequently costs to industry, and thus society as a whole in IDCs, will be significantly greater. There is a need to gain greater insight into the prevalence of pushing and pulling tasks in IDCs as well as the injury rate, and cost of injury, in order to improve the working environment and ultimately, productivity.

Biomechanics of pushing and pulling

Pushing and pulling can be defined as being the exertion of a hand force where the major component of the resultant force is directed horizontally, by someone on an object or another person (Baril-Gingras and Lortie, 1995). In order to differentiate between pushing and pulling, pushing is defined as being when the hand force is directed away from the body, while pulling is defined as when the force is directed towards the body (Hoozemans *et al.* 1998). 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 the initial force required to accelerate the object, the sustained force to keep the object moving, and the force required to bring the object to a stop.

Despite the obvious attractions of manual materials handling devices to reduce the risk of the development of musculoskeletal problems, and the now widespread use of trolleys in all types of industrial organisations, Mack *et al. (*1995) argued that little attention has been given to the ergonomics aspects of their design. The same risks that apply to the assessment of lifting tasks, still remain when using handling devices, as they still require the operator to exert force. Mack *et al.* (1995) caution that the use of mechanical aids without the appropriate attention to ergonomic factors may result in them causing more problems then they were intended to solve. Chaffin (1987) identified two types of hazards relating to pushing and pulling which are likely to lead to injury or musculoskeletal complaints. Firstly if there is a mismatch between the task demands and the worker capabilities it is likely that the musculoskeletal system may become physically overexerted. Secondly, due to the nature of pushing and pulling tasks, they are associated with an increased likelihood of slip, trip and fall accidents, which can cause injuries to the musculoskeletal system. Winkel and Mathiassen (1993) contend that in terms of work-related factors when looking at the relationship between health complaints and pushing and pulling there are three factors which need to be taken into consideration. These factors are the intensity which incorporates the amplitude and direction, the frequency and the duration of the task. If one of these factors diverges from its optimal value, the risks of developing musculoskeletal disorders is increased.

Some authors have argued that there are several other problems associated with the use of mechanical aids. Mathisson *et al.* (1994) found that time pressures on the assembly line often led to the handling devices not being used, even when the operators were aware of the increased risk of musculoskeletal injury. Mack *et al.* (1995) argued that mechanical aids tend to be slower than simply moving the load by hand. It is evident that there is a multitude of factors which need to be taken into account when looking at the design and usability of manual carts. Jung *et al.* (2005) argued that the factors which interact with usability can be grouped into four categories; namely, design, task, environment and user (see Figure 1).

Furthermore there are other factors that need to be taken into consideration. Resnick and 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.

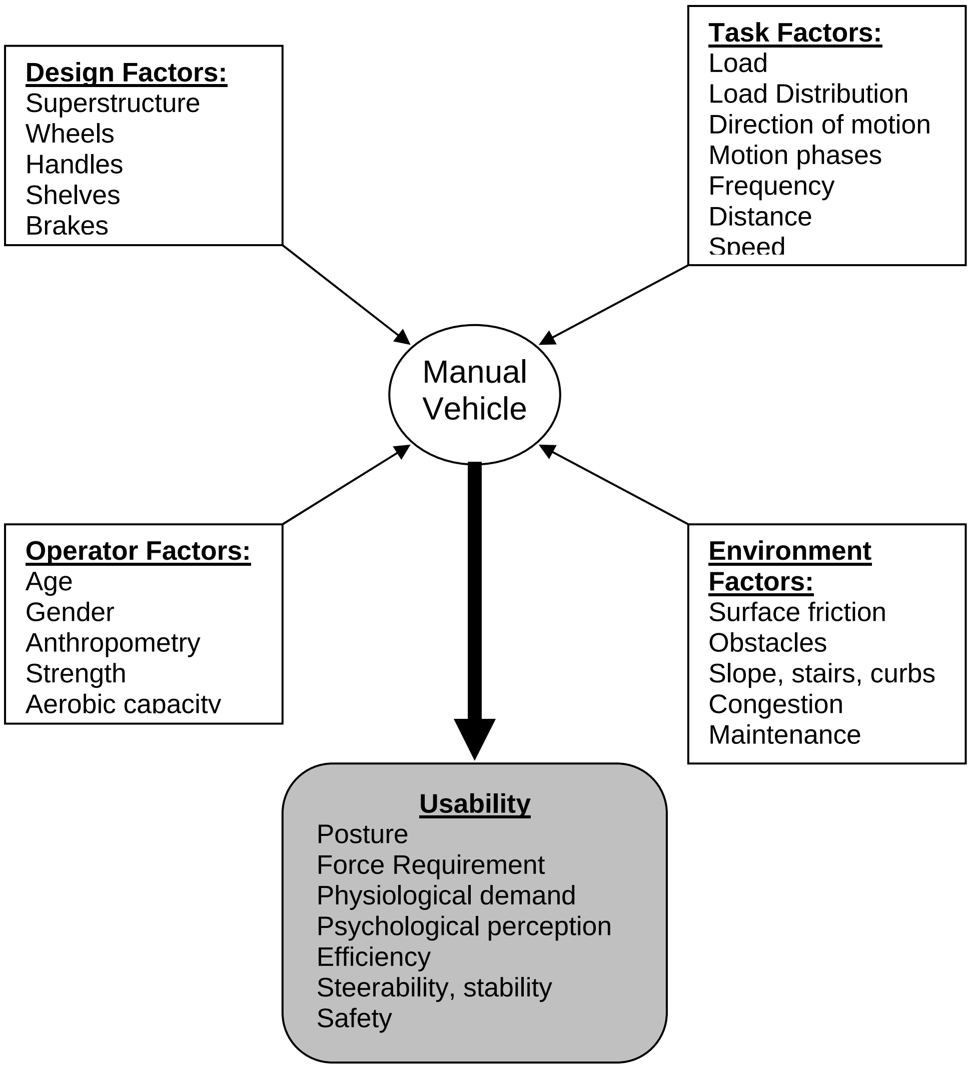

Figure 1: **Factors to consider in the usability of manual vehicles**
(Adapted from Mack *et al.,* 1995, and Jung *et al.,* 2005)

Force and Posture

The high occurrence and cost of occupational injuries due to overexertion during pushing and pulling activities in industry is clear (Warwick *et al.,* 1980; Lee *et al.,* 1991). The main focus of research into the risks associated with pushing and pulling tasks has been aimed at the assessment of the forces exerted at the hands (Hoozemans *et al.,* 1998; van der Beek *et al.,* 1999; Kingma *et al.,* 2003). As early as 1983 Chaffin and co-authors identified that pushing and pulling capability is dependent on the interaction between subject anthropometrics, postures and shoe/floor friction. Daams (1993) agreed that working posture plays an important role in determining the maximal force which can be exerted. Although the impact of working posture has been investigated by several authors, the research tends to have been limited to standard, static working postures. Resnick and Chaffin (1995) argued that studies on pushing and pulling forces have initially focused on the exertion of static forces in the sagittal plane. In reality it could be argued that workers in all industries are seldom required to exert static push-pull forces in a single plane. Most pushing and pulling tasks are going to be dynamic, requiring workers to move loads over a distance and in more than a single plane.

Lee *et al.* (1991) argued that the assessment of dynamic pushing and pulling is more complex than under static conditions. These authors contend that under dynamic conditions workers have to be ready to regain balance in case the trolley moves unexpectedly. During static pushing and pulling the worker's body is fully supported by the static object, however this may not be the case during dynamic tasks. The associated potential lack of stability results in workers taking smaller steps or adopting awkward working postures, increasing the risk of over-exertion injuries.

The loads moved during pushing and pulling tasks in IDCs remain substantially higher than those required in Industrially Advanced Countries (IACs), often requiring workers to adopt awkward working postures in order to achieve the required force output (Todd and James, 2004). Martin and Chaffin (1972), Chaffin *et al.* (1983) and Lee *et al.* (1991) all found that posture plays a critical role in both the magnitude of the peak horizontal forces which subjects are capable of exerting, and the stresses on the lower spine. Chaffin *et al.* (1983) found that the postures which individuals adopt in order to push or pull are dependent on a number of factors including the hand location (handle height) and shoe/floor friction. This high force requirement and the poor working postures adopted by workers during pushing and pulling tasks are likely to lead to an increase in musculoskeletal injuries and the likelihood of slip, trip and fall accidents.

Handle height

The optimal handle height has been of considerable interest amongst researchers investigating pushing and pulling, yet there is a lack of agreement as to what is optimal, as illustrated by the results presented in Table 1. Chaffin *et al.* (1983) found that by reducing handle height the compressive forces at the lower back were increased, while almost a decade later Lee *et al*. (1991) argued that during pulling an increase in handle height resulted in an increase in the spinal compressive force, but appeared to have no impact on spinal forces during pushing. Van der Woude *et al.* (1995) concurred with Lee *et al.* and found that increasing handle height had no impact on lower back compressive forces, although it did reduce the net moment around the shoulder.

The lack of consensus with regard to optimal handle height is highlighted by the review paper by Snook and Ciriello (1991). These authors concluded that for males pushing the maximal initial force was highest at the middle height. Contrastingly for females as handle height increased so did the maximal initial force. For pulling, as the handle height was reduced so the maximal initial force increased. When looking at sustained forces they concluded that there was no difference in sustained pushing force at different handle heights, but that during pulling as the handle height was dropped so the maximal sustained force increased. There is evidently a need for future research to clarify the findings regarding optimal handle height for both pushing and pulling tasks in order to minimise the risk of placing excessive strain on the musculoskeletal system, while at the same time minimising the likelihood of slip, trip and fall accidents.

Table I: **Summary of studies of handle height showing conditions under which maximal force (Fmax) is produced.**

Authors, date	Findings	Recommended handle height
Martin and Chaffin (1972)		50 – 90 cm above the floor
Ayoub and McDaniel (1974)	Increase H increases Fmax	Pushing = 91 – 114 cm Pulling = 94 – 115 cm
Warwick *et al.* (1980)	Push: increase H increases Fmax Pull: reduce H increases Fmax	
Chaffin *et al.* (1983)	Decrease H increases Fmax	Between shoulder and hip
Gagnon *et al.* (1992)	Reduce H increases Fmax	
Lee *et al.* (1992)	Push: Increase H increases Fmax Pull: reduce H increases Fmax	
De Looze *et al.* (1995)		
Kumar (1995)	Fmax greatest at middle H	
Fothergill *et al.* (1999)	Pull: reduce H increases Fmax	

Handle Angle

There have been very few studies to date which have investigated the impact of trolley handle angle of pushing and pulling performance. Drury and Pizatella (1983) found hand deviation to be the accommodating mechanism between a handling aid and the worker and that it is potentially damaging. Okunribido and Haslegrave (1999) 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. This study was conducted on a two wheeled trolley, as yet no studies appear to have looked at the impact of handle angle of forces during pushing or pulling of four wheeled trolleys.

Wheels

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.,* 1999). Similarly David and Nicholson (1985) found that larger wheels resulted in 43% reduction in intra-abdominal pressure. Al-Eisawi *et al.* (1999) further concluded that the minimum initial forces are required when all four wheels are aligned in the forward direction, but that there was a 31% increase in the forces required for straight pushing and pulling when all four wheels swiveled.

Load

The size of the load moved is an important factor as it has a close correlation with the forces required to move the trolley. Resnick and Chaffin (1987) contend that due to biomechanical criteria the load moved in a four wheeled container should not exceed 225 kg. They further recommend that loads should not exceed 114 kg for two-wheeled carts. However, cognisance must be taken of the fact that there are many other factors which influence the forces required to move trolleys other than the load, and under some circumstances loads significantly lower may be seen as excessive. Regardless of the ‘other’ factors involved van der Beek *et al.* (2000) argued that the loads moved should be kept as low as possible. Kingma *et al.*

(2003) recently suggest that the centre of mass of the load should be close to the wheel axes and kept as low as possible.

FUTURE DIRECTION

Pushing versus pulling

The literature is unclear on whether pushing or pulling results in the greatest force production, with Al-Eisawi *et al.* (1999) arguing that the results of research on push and pull strength have not been consistent. Several authors have argued that pulling forces are greater than pushing forces under static conditions (Davis and Stubbs, 1977; Kumar, 1995). However, some authors under similar conditions found no differences between pulling and pushing (Keyserling *et al.,* 1980; Daams, 1993). Furthermore the responses to dynamic pushing and pulling are even less conclusive, with push being greater than pull (Snook and Ciriello, 1991), pull greater than push (Lee, 1982) and no differences (Ciriello *et al.,* 1993). Lee *et al.* (1991) found that in terms of the strain experienced at L_5/S_1, pulling placed almost double the strain on this joint than pushing.

Additional problems are evident in the lack of stardardised methodology in push-pull research, as Daams (1993) contended that the methods of description tend to vary substantially. Although standardised positions may have been used, the descriptions of posture vary greatly from paper to paper. Al-Eisawi *et al*. (1999) argued that studies have employed different postures and also imposed different restrictions on the posture adopted during experimentation. It is evident that further research into this field is imperative in order to create a clearer understanding of the forces involved in pushing and pulling in industry in order to make recommendations that are likely to maximize the efficiency of the human operator.

Gait patterns

Menz *et al.* (2003) and Cordero *et al.* (2003) argued that the maintenance of stability for the human postural control system is a difficult task for several reasons. The first reason is that the centre of mass is located a considerable distance away from the support surface, and secondly because during a significant period of the gait cycle the body is supported by a single leg where the centre of mass passes outside of the base of support. Therefore these authors contend that the potential for loss of balance while walking is considerable. This potential risk is dramatically increased when required to push and pull objects, due to the variety of postures adopted resulting in the centre of mass falling further outside of the base of support (Todd and James, 2004).

Furthermore Resnick and Chaffin (1995) maintain that when movements during pushing and pulling are dynamic, postures and forces can change rapidly during the course of the exertion, with subjects seldom being able to assume optimal postures for the duration of the task. The end result is a substantial increase in the risk of slip, trip and fall accidents (Chaffin, 1987) during pushing and pulling tasks. Although biomechanical analysis offers a sound understanding of gait pattern responses to walking and running under varying conditions, as yet no attempt has been made to investigate the gait pattern responses to pushing and pulling tasks. Any information relating to changes in gait patterns during pushing and pulling activities would go a long way to helping us understand the mechanisms involved in slip, trip and fall accidents while using manual materials handling devices.

PHYSIOLOGY

The main focus of research into pushing and pulling activities has undoubtedly been on the biomechanical stressors placed on the musculoskeletal system. There have been very few studies investigating the physiological responses to pushing and pulling. 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, in 1987 Nijenhuis and Roseboom found similar responses for wheeled cages. Very few studies have focused on the impact of handle height on heart rate and oxygen consumption during pushing and pulling, and found no difference in these responses (Ciriello and Snook, 1983). From subjective ratings of fatigue, Ayoub and McDaniel (1974) argued that handle heights should be as low as possible and the foot placement distance as large as possible.

Van der Beek *et al.* (2000) investigated pushing versus pushing and found that oxygen consumption was higher in pulling than pushing for both males and females and at all masses tested. However, these results should be tentatively accepted as these authors only tested four male subjects and eight female. These authors also examined sex-related differences and found that when corrected for differences in mass, stature and maximal oxygen consumption there were no significant sex-related differences overall, although differences in heart rate and oxygen consumption were evident without correction for personal factors.

Future needs

It is clear that there is a lack of studies investigating the physiological responses to pushing and pulling tasks in industry. More comprehensive studies with a greater number of subjects are needed in order to gain a more comprehensive understanding of the human responses to physically demanding pushing and pulling activities. Although several studies have suggested that from a biomechanical perspective it is better to push than to pull, as of yet there is little evidence from a physiological perspective to support this evidence. The majority of the physiological studies have been conducted under laboratory settings and there appears to have been no real effort made to gain an understanding of the physiological demand of pushing and pulling tasks *in situ*. In order to better understand the mechanisms of fatigue in industry it is imperative that we gain a better understanding of the physiological demands of pushing and pulling. Ergonomic design factors relating to the design of carts need to be considered not only from a biophysical perspective, but also from a physiological perspective.

CONCLUSION

Most research into MMH has been based on the mainly Caucasian populations of Europe and North America, which may lack applicability to the working populations found in IDCs which are characterised by a diversity of cultures and races. Wu (2003) argued that the problems associated with MMH are more severe in developing countries and that further research on the populations of these countries is needed. Mack *et al.* (1995) asserted that improvements to manual materials handling devices need to be approached via two routes; firstly there needs to be greater attention given to the ergonomics aspects of their design, and secondly there needs to be clear guidance for the selection of aids for particular tasks and environments. Dempsey (1998) emphasised that in order to understand human responses to physically demanding task it is essential to take a holistic approach. The clouding of the relationship between pushing and pulling and musculoskeletal disorders needs to be addressed by taking a holistic, integrated approach to the assessment of the demands placed on the musculoskeletal and cardiovascular systems of the body. Marras (2000) emphasised the importance of systematically examining the body of knowledge from all related disciplines that can be used to assess causality and to control the physical factors associated with work, in order to optimise the working environment.

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