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# Schoolbag carriage: design, adjustment, carriage duration and weight.

A thesis presented in  
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# Abstract

There is anecdotal and scientific evidence to suggest that schoolbag carriage is associated with musculoskeletal discomfort (MSD) and possibly long-term back pain. Thus schoolbag carriage is an area of concern for students, parents and both education and health professionals. A schoolbag weight limit of 10% of body weight (BW) is currently recommended. However, it is based on subjective observations rather than objective findings and does not consider other aspects of schoolbag carriage such as schoolbag design and adjustment or carriage patterns. Five studies were conducted in order to determine the effects on students' responses to schoolbag carriage of schoolbag design, adjustment, carriage duration and weight. Backpack design had a significant effect on reported musculoskeletal discomfort and choice of backpack. Schoolbag hip-belt and shoulder strap adjustment and weight significantly affected shoulder strap tension forces and shoulder interface pressure in simulated schoolbag carriage. Using activity monitoring, school students were found to spend approximately two hours carrying their schoolbags each day. This usually comprised 11-15 times per day of 8-9 minutes of carriage. Using this temporal pattern information, 16 boys (13-14 years) were exposed to a simulated school day using schoolbags weighing 0, 5, 10, 12.5 and 15% BW and an additional condition of 10% BW with tighter shoulder straps. Posture, rating of perceived exertion (RPE), muscular strain and reported ability to walk and balance were significantly affected when schoolbag load reached 10% BW. However, despite these findings, the magnitude of self reported muscular strain and MSD suggested that 15% BW may be too heavy for school students. Thus, 10% BW may be an appropriate upper schoolbag weight limit for a typical school day. Using a psychophysical approach the mean (standard deviation) maximum acceptable schoolbag weight (MASW) selected by 16 school boys (13-14 years) was 10.4(3.8) %BW. This finding agrees with the findings of the previous study and supports the current schoolbag weight recommendation of 10% BW. The results of the five studies can be used in developing schoolbag carrying guidelines to help reduce the prevalence of MSD amongst school students.

# Acknowledgements

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My wife, Julia, has put up with a lot, but has always been supportive and diplomatic. Julia has basically kept a family of three ticking along for the past 19 months and has accepted my absences (both physically and mentally) by ‘digging in’ when times were tough. However, Julia has a very astute memory and it may take me three to four years to repay the debts!

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Lastly, I also owe thanks to the team at the Ergonomics lab at Queens University in Ontario, Canada. In particular, Joan Stevenson was extremely welcoming in allowing me to use their load carriage simulator for the data collection for chapter 3. Sue Reid also offered substantial technical support.

## List of publications from thesis

- Mackie, H. W., Legg, S. J., Beadle, J. and Hedderly, D. I. (2003). Comparison of four different backpacks intended for school use. *Applied Ergonomics*, 34, 257-264.
- Mackie, H. W., Legg, S. J. and Beadle, J. (2003). Development of activity monitoring for determining load carriage patterns in school students. *Work: A Journal of Prevention, Assessment, & Rehabilitation*, 22, 231-237.
- Mackie, H. W., Stevenson, J. M., Reid, S. A. and Legg, S. J. (2004). The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. *Applied Ergonomics*, 36, 199-206.
- Mackie, H. W. and Legg, S. J. (2004). Measurement of the temporal patterns of schoolbag carriage using activity monitoring and structured interview. *Ergonomics*, In Press.
- Mackie, H. W. and Legg, S. J. (2004). Postural and subjective responses to realistic schoolbag carriage. *Submitted to Ergonomics*.
- Mackie, H. W., Legg, S. J. and Walt, S. E. (2004). A psychophysical approach to determining an upper schoolbag weight. *Submitted to Applied Ergonomics*.
- Mackie, H. W., Stevenson, J. M., Reid, S. A. and Legg, S. J. (2003). Responses to schoolbag carriage. Proceedings of the XVth Triennial Congress of the International Ergonomics Association. Aug 24<sup>th</sup>-29<sup>th</sup>, Seoul, South Korea.

# Thesis structure

This thesis comprises five studies addressing the effects of schoolbag design, adjustment, carriage duration and weight on students' responses to schoolbag carriage. Each study forms an individual chapter of the thesis (chapters 2-6). These five chapters are preceded by an introduction to the thesis topic and chapter 1, which is a review of literature. This builds a rationale for the thesis aim.

Each study (chapters 2-6) is preceded by a preface. This describes the relevance of each study to the rest of the thesis. All of the studies have been published as papers in, accepted for publication in, or submitted to a journal of international scope and quality. The style of each of these chapters is in the style of the journal to which the paper has been submitted, except for heading formats. Each study is reproduced in its entirety except for the tables and figures, which have been embedded in the text and the table and figure legends which are located as a list for the whole thesis after the table of contents and list of appendices for the thesis. In some cases, 'In press' references have since been published. In these cases the most recent version of the reference is included in the main reference list for the thesis. A discussion (chapter 7) links the findings of each of the studies to create the overall thesis findings and conclusions. A post-script follows chapters 2, 3 and 4, providing additional information that would not be considered necessary for a journal article, but is necessary to provide the required depth of a thesis. Also, in some cases examiners comments are addressed in the post-scripts.

Following the thesis conclusions and references, the appendices for each study are included. Additional information that was not included within each submitted study, including summarised or raw data, is supplied. All summarised and raw data are supplied on a CD that is attached to the inside back cover of this thesis. Included in the appendices to chapter 4 is a methodological study that has been quality assured and published in a journal.

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Development of activity monitoring for determining  
load carriage patterns in school students. *Work: A  
Journal of Prevention, Assessment, & Rehabilitation*,  
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# *Introduction*

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School students usually carry their belongings to, from and around school each day. Textbooks, lunch, sports equipment, jackets, musical instruments and more recently laptop computers are among the items that may be carried. Cumulatively, these items can represent a substantial weight.

There has been considerable concern from students, parents and both education and medical professionals regarding schoolbag carriage. More specifically, the weights of schoolbags and the lack of availability of lockers appear to be of greatest concern. It is believed that heavy schoolbags may predispose students to musculoskeletal discomfort (MSD\*), particularly in the lower, middle and upper back and neck regions. An absence of lockers in schools means that students must carry their belongings for longer durations, which may add to a students' risk of developing MSD.

In both scientific and general media, schoolbag weight appears to receive a disproportionately high amount of attention when compared with other schoolbag carriage factors such as schoolbag design and adjustment, and duration and frequency of carriage. Furthermore, 10% of bodyweight (BW) has been commonly accepted as a recommended schoolbag weight limit despite a lack of scientific evidence to support it.

School students that are beginning high school (approximately 13 years of age) appear to be at the most risk of exposure to physically demanding schoolbag carriage. In contrast to primary school where all of students' subjects are taught in a single classroom, high school students move between classes with their schoolbags in order to attend different lessons. In addition primary students are smaller and tend to carry heavier backpacks compared to older high school students when backpack weight is expressed a percentage of bodyweight. Students in their first

\* For the purpose of this thesis the term Musculoskeletal discomfort (MSD) will be used to describe musculoskeletal pain, discomfort or injury, particularly in the neck, shoulders and upper, middle and lower back regions. However, when the results of specific studies are being reported, the terminology specific to that study is used.

years of high school also tend to be experiencing puberty and sudden growth changes, which may also affect their schoolbag carrying ability.

The physical demands of schoolbag carriage are likely to depend not only on schoolbag weight. Schoolbag design, schoolbag adjustment, duration and frequency of carriage and the manner in which the weight is carried all affect the demands on the musculoskeletal system and may affect a students' susceptibility to MSD. Also, despite the fact that 10% BW is already commonly recommended as a schoolbag weight limit, scientific evidence for this or an alternative limit needs to be demonstrated so that evidence-based recommendations for schoolbag carriage can be developed in the future.

This thesis explores the influences of schoolbag design, schoolbag carriage adjustment, the temporal patterns of schoolbag carriage and schoolbag weight on students' responses to schoolbag carriage. In addition, it provides evidence to support an upper recommended schoolbag weight.

Although the first published study of schoolbag carriage was in 1965, it is only in recent years (1997 onwards) that there have been a number of quality assured studies published which have specifically addressed schoolbag carriage. In the next section (chapter 1), the scientific literature concerning schoolbag carriage, along with literature from supporting areas are examined and the rationale for the thesis aim is developed.

# Chapter 1

## *Review of literature*

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### **Introduction**

The purpose of the following review of literature is to build a rationale for the thesis aim. This is achieved by a review and critique of the relevant literature in six areas\*:

1. Manual handling guidelines
2. Adult load carriage
3. The physical capability of school children
4. Schoolbag carriage and reported MSD
5. The physical demands of schoolbag carriage

A brief explanation of the relevance of each of the five literature review areas follows:

### **1. Manual handling guidelines**

There are currently no comprehensive evidence-based guidelines for schoolbag carriage that are based on scientific research. This may be part of the reason that schoolbag carriage has become an issue. An upper schoolbag weight of 10% of bodyweight (BW) has long been proposed. However, there is no evidence for this limit. Moreover, the predominant focus of both schoolbag carriage recommendations and previous research has been schoolbag weight. Other factors such as schoolbag design, adjustment and carriage duration may also have an effect on the demands placed on the user, yet there are no evidence-based recommendations for these. Very little research has been carried out in these areas. Current manual handling guidelines indicate that the physical demands of manual handling depend not only on load weight but also on posture, movement, frequency and duration. Schoolbag carriage is a subset of manual handling. Therefore factors other than schoolbag weight should be included in schoolbag carriage recommendations.

\* Literature specifically relating to methodologies used in this thesis will be critiqued within each relevant chapter.

## **2. Adult load carriage**

There is a wealth of studies addressing load carriage by adults. There are very few for load carriage by children. The studies of adult load carriage will be reviewed and critiqued as much of the information derived from them will help to predict how school students might respond to varying schoolbag carriage conditions. Also, many of the methods used to study adults' responses to load carriage are applicable to schoolbag carriage.

## **3. The physical capability of school children**

School students' responses to load carriage may differ from that of adults. Part of the concern regarding schoolbag carriage is that the size and shape and therefore the physical capabilities of school students, vary considerably. These are also different from adults as a result of their growing skeletons. For this reason, the literature that addresses the physical capability of school children will be addressed, so that the appropriateness of applying adult load carriage and manual handling principles to schoolbag carriage may be evaluated.

## **4. Schoolbag carriage and reported MSD**

The development of schoolbag carriage guidelines has assumed that schoolbag carriage, in some cases, contributes to the development of MSD. In order to provide more substantial evidence of this link, a number of epidemiological studies have included schoolbag carriage as a possible determinant of school students' MSD. These studies will be examined and a summary of the current evidence about a link between schoolbag carriage and MSD will be given.

## **5. Student responses to schoolbag carriage**

The physiological, postural and gait studies that address students' responses to schoolbag carriage have added to our understanding of the physical demands of schoolbag carriage. In addition, these studies have provided limited evidence for estimating weight limits for schoolbags. However, a critique of this literature is needed because much of the focus has been on load weight per se. No studies have

provided conclusive evidence that an upper schoolbag weight exists. This proposition forms the basis for the aim of this thesis, which is stated at the conclusion of the review of literature.

## **1. Manual handling guidelines**

The topic of schoolbag carriage is a subset of the much broader theme of manual handling. Normally, manual handling evaluations are associated with adults working in industrial situations. As a result of the high incidence of injury associated with manual handling tasks, many government organisations have developed regulations, guidelines and codes of practice for manual handling tasks (International Labour Office (ILO) 1988, Department of Labour 1991, National Occupational Health and Safety Commission 1990, Health and Safety Executive 1992, Victorian WorkCover Authority 2000).

There is a wealth of guidance material relating to manual handling tasks that are based on one of four main approaches to determining manual handling limits. The approaches are biomechanical (Andersson 1985, Chaffin et al. 1988, Marras et al. 2003), physiological (Samanta and Chatterjee 1981, Mital et al. 1982, Legg and Pateman 1984), psychophysical (Morrissey and Liou 1988, Ayoub and Dempsey 1999, Snook 1999) and epidemiological (Stubbs et al. 1983, Garg and Moore 1992, Dempsey and Westfall 1997). None of these approaches have been entirely appropriate for all manual handling tasks.

In 1981 the National Institute for Occupational Safety and Health (NIOSH) developed an equation to assist in the evaluation of lifting tasks in the sagittal plane (NIOSH 1981). The equation was based on biomechanical, physiological and psychophysical criteria, which were derived from the previous literature related to manual lifting in industrial situations in the three areas. The equation provides an empirical method for determining a weight limit for manual lifting. In 1991 the equation was updated to accommodate asymmetric lifting tasks (Waters et al. 1993). Three main points underlie the biomechanical criteria for the NIOSH lifting equation (Waters et al. 1993). Firstly, it has been demonstrated that the lumbar spine

(lumbosacral joint) is the most vulnerable part of the spine to injury as a result of lifting. Secondly, compressive force in the lumbosacral joint is more likely to cause injury than other force vectors. Lastly, 3.4 kN has been established as a compressive force that is associated with an increased risk of lumbosacral injury. However, there appear to be no studies that describe how these principles should be adjusted for adolescents or children. The vertebral discs and supporting ligaments and muscles may be proportionately weaker in children, and therefore lifting might pose a relatively greater risk for children. It is more certain that the epiphyseal plates of children and adolescents are areas of relative weakness. This area will be addressed later in the chapter in 3. *The physical capabilities of school children.*

Similarly, three points define physiological criteria for manual handling limits. A limit of 9.5 kcal/min for maximum aerobic lifting capacity has been established for repetitive lifting tasks. For work that mainly requires arm work, 70% of maximum aerobic capacity is proposed as an energy expenditure limit. Lastly, three percentages (50, 40 and 33%) of maximum aerobic lifting capacity, for lifting tasks lasting 1 hour, 1 to 2 hours and 2 to 8 hours respectively, have been recommended.

The psychophysical criterion chosen by NIOSH for manual handling tasks is that the job demands posed by manual lifting would not exceed the lifting capacity of about 99% of male workers and 75% of female workers. The psychophysical approach to evaluating manual handling tasks is based on a subjective perceptual method that identifies a ‘maximal acceptable weight of lift’. This is believed to provide an estimate of the combined effects of biomechanical and physiological stressors of manual lifting (Waters et al. 1993).

The psychophysical approach to determining a maximum acceptable weight of lift (MAWL) was developed by Snook and Irvine 1966. Using Snook’s experimental methodology, participants are given control over one task variable (typically the load to be handled) while the rest are controlled. The participants (who are volunteers representative of industrial workers) are then asked to work as hard as they can on an incentive basis “without straining or becoming unusually tired, weak, out of breath or overheated”. Participants initially lift a very light load or a very

heavy load based on a randomized design, which is then adjusted by adding or removing weight. The mean of the two weights is then calculated to determine the MAWL, as long as there is not more than 15% difference between the two final weights. This methodology could easily be modified to determine an estimate for a maximum acceptable schoolbag weight. Using school students' own perceptions of schoolbag lifting and carrying might be a useful approach in attempting to determine an upper limit for schoolbag weight, especially if the results were to be used in conjunction with objective measures.

Although the biomechanical and physiological demands of schoolbag carriage can easily be determined, there are no accepted limits for schoolbag carriage based on previous research. This makes it difficult to estimate the relative risk of the stresses associated with schoolbag carriage. The NIOSH guidelines are based on adult data and do not allow for the differences in physical capability between adults and children. Therefore the applicability of the NIOSH guidelines to children is inappropriate. In addition, the NIOSH guidelines are based on lifting only and do not account for the combination of lifting and load carrying that school students must perform when handling their schoolbags. Despite these limitations, estimates of the demands of schoolbag carriage could be made using the adult based criteria in the NIOSH guidelines. If the demands of schoolbag carriage were to approach adult limits then there would be cause for concern as school students have a lower physical capacity than adults (see page 23).

The maximum weights that should be lifted and carried has been reported (ILO 1988). Recommendations from many countries are included in the ILO report and there is a section relating specifically to young working persons and children. Table 1 includes countries from the ILO report that specify load lifting or carrying limits for persons aged up to 16 years. This age limit has been selected as it most closely relates to children that are most likely to be carrying schoolbags.

**Table 1.** Weight limits for different countries for boys and girls aged up to 16 years involved in manual materials handling tasks (ILO 1988).

Country	Conditions	Maximum weight (kg)	Maximum weight (kg)
		Boys	Girls
Bolivia	Not specified	10	5
Columbia	Not specified	15	8
Cote d'Ivoire	Not specified	15	
Czechoslovakia	Occasional carrying	10	10
Ecuador	Not specified	16	
Egypt	Carrying	16	7
Greece	Lifting/carrying	5	5
Hungary	Lifting/carrying	15	
Israel	> 2 hours/day	10	
Japan	Lifting/carrying/intermittent	15	12
Malaysia	Carrying	15	8
Mexico	Carrying	20	10
Pakistan	Lifting/carrying	16	
Poland	Carrying on flat surface	16	10
	Mean(standard deviation)	14(4)	8(2)

The mean lifting/carrying limit for boys up to 16 years is 14 kg. For a 60 kg boy this would represent 23% of their bodyweight (BW). The mean lifting/carrying limit for girls up to 16 years is 8 kg. For a 55 kg girl this would represent 15% BW. Despite lifting/carrying limits being specified for many countries, the ILO report does not cite any published studies to support these limits.

In the UK, The Manual Handling Operations Regulations (Health and Safety Executive, 1998) contain guidelines for maximum loads to be lifted. However, these guidelines only provide an initial filter upon which a decision can be made as to whether a more detailed ergonomics risk assessment should be carried out. The guidelines do not address loads lifted or carried specifically by children or

adolescents. Whittfield et al. (2004) applied these guidelines to the task of lifting a schoolbag from the floor and determined a guideline upper weight of 4.5kg. However, Whittfield et al. (2004) provide no details about how they arrived at this number given that the regulations are for adults. Nevertheless, this figure is far lower than the schoolbag loads that were being carried by students in Auckland schools in Whittfield et al.'s study (7.0kg for 13 year olds and 6.3kg for 16 year olds). This raises concern about the magnitude of schoolbag weights that are being lifted by students.

In Australia, the Federal government has published a national standard for Manual Handling (National Occupational Health and Safety Commission 1990). The National Standard states that age is one of the factors that shall be taken into consideration when assessing the risk associated with manual handling. However, no specific guidelines are given regarding children's manual handling. In the Australian state of Victoria, the Code of Practice for Manual Handling (Victorian WorkCover Authority 2000) was published to provide practical guidance in order to help employers comply with the Occupational Health and Safety (Manual Handling) Regulations 1999. Within the code of practice it is stated that "The muscular effort required to lift, lower or carry a load depends on more than just the weight of the object. It is also determined by the postures, movements, forces, frequency and duration involved in the task". Consequently, no maximum weight limits are given and much more emphasis is placed on identifying risks and hazards. Interestingly, the age or physical capability of workers is not mentioned as a source of risk in either the regulations nor the code of practice. Also, the code of practice is targeted at the adult workforce and is not applicable to schoolbag carriage.

In New Zealand, the Department of Labour (1991) specify a weight limit of 16kg for workers under 18 years of age based on the rationale that young workers are at greater risk of manual handling injuries than adult workers because they are still developing physically. However, this weight limit does not appear to be based on any objective evidence. In 2001 the Department of Labour's Occupational Safety and Health Service published a code of practice for manual handling. The document

does not address manual handling limits for children nor considers that differences in physical capability between adults and children may influence limits for children.

## Schoolbag carriage guidelines

In 1997 the National Back Pain Association (UK) conducted a schoolbag survey and reported that school students should carry no more than 10% of their body weight (NBPA 1997). However, there is only limited agreement with this recommendation (Maholtra and Sen Gupta 1965, Voll and Klimt 1977, Sander 1979), none of which provide objective evidence for their support.

Maholtra and Sen Gupta (1965) studied the energy cost and heart rate of six male school students aged between 9 and 15 years resulting from carrying schoolbags (2.7 kg) in different positions while walking on a treadmill at 2.5 mph. Hand carrying was found to be consistently more demanding than carrying a backpack using straps over both shoulders. They stated that “The weight usually carried by a student is not likely to exceed 10-12% of the body weight”, although their study did not provide specific data to support this assumption. In a study of 1522 school students across four classes (1<sup>st</sup> – 4<sup>th</sup> grade, no ages were given), Voll and Klimt (1977) measured school bag weights (11%-14% BW), mode of carriage, distance travelled to school and each students’ packing habits. More than 50% of the students reported their schoolbag as being too heavy or quite heavy. The majority wore their schoolbags on their back using both shoulder straps. It was also mentioned that a regional school council recommended that the schoolbag weight should not exceed 11%-13% BW and that a “scientific delegation” considered that schoolbag weight should be less than 11% BW. Sander (1979) measured and compared schoolbag weights across four primary school classes. Sander stated that “In the opinion of the orthopaedic doctors, the weight of the bag should not exceed one tenth of the body weight of the student”. Although these studies support a schoolbag weight limit of approximately 10% BW, none of them provide objective evidence to substantiate their recommendations.

More recently, internet based school ergonomics guidelines have been published, aimed at reducing MSD as a result of backpack carrying, sitting, computer work and

other school related activities (Government of South Australia 2002). Part of the guidelines recommends that carrying a backpack should not significantly alter young peoples' posture from the side and front view, backpacks should be worn over two shoulders and that backpack weight should not exceed 10% BW. Again, there is no specific evidence to support the recommended load weight of 10% BW. However, it is understandable that organisations would want to implement guidelines for load carriage despite a lack of objective information to support them. One of the principal authors of the South Australian government guidelines has recently suggested that a limit of approximately 8% BW might be more appropriate based on some, as yet, unpublished studies by her research group (personal communication, Grimmer, September 2004).

Similarly, the Ergonomics for Children and Educational Environments (ECEE) technical committee of the International Ergonomics Association (IEA) has published guidelines for computer use (IEA 2003), but have not yet published guidelines for any other school activities. The lack of guidelines in areas other than computer use might be because an international technical committee such as this tends to insist that any guidelines published under its auspices must be supported by objective research.

The first review of studies that contribute to recommended weight limits for schoolbag carriage (Brackley and Stevenson 2004) has recently been published. A schoolbag weight limit of 10-15% BW is recommended by the authors based on the findings of current literature. However, the findings of the physiological and biomechanical studies that contribute to this recommendation (see pages 31-36) support weight limits of 10-20% BW. This range is broad and further work is required to define a more precise schoolbag weight limit.

In summary, there are various international guidelines for manual handling tasks. However, in most cases the guidelines are not intended for children. When manual handling guidelines exist for children, they are not based on the findings of quality assured research. More recently, quality assured studies have provided evidence to support weight limits for schoolbag carriage which should provide the basis for

sound schoolbag carriage guidelines in the future. However, the findings of these studies vary. Thus, more research is required in order to bring greater certainty to a recommended maximum schoolbag weight and to determine the effects of other factors such as schoolbag design, adjustment and carriage duration.

## 2. Adult load carriage

Before attempting to draw conclusions from schoolbag specific literature regarding the conditions that may lead to MSD in school students, much can be learned from the more substantial literature addressing the demands of adult load carriage and more specifically backpacking. This is an especially valid link as a high proportion of students choose to use backpacks as schoolbags (Grimmer and Williams 2000, Whitfield et al. 2001, Jones et al. 2003).

### Introduction

Historically, most adult load carriage studies have been of military load carriage (Cathcart 1923, Lippold and Naylor 1950, Marshall 1950, Renbourne 1954, Legg 1985, Legg and Mahanty 1985, 1986, Haisman 1988, Duggan and Haisman 1992, Legg et al. 1992, Knapik 2004). This is understandable given the severe backpacking demands placed on soldiers in their duties and the ready availability of soldiers as participants in studies. Renbourne (1954) described the development of the ‘rucksack’ for military purposes, including modification of equipment as a result of injury and discomfort. Renbourne cites critical evaluation of backpacks occurring as early as 1631.

The focus of the earliest studies of backpacking was the determination of energy expenditure. Cathcart et al. (1923) calculated energy expenditure in order to determine the most efficient load to be carried by soldiers. Disproportionate increases in Oxygen intake per minute and Calorie cost per minute were demonstrated when greater than 40% of BW was carried. Based on these results it was recommended that 40% of dressed body weight was the ‘optimal’ (maximum load without significantly affecting energy expenditure) load that soldiers could

carry when walking at 5-6 km/hr. However, the results must be treated cautiously as only two participants (Royal Army Medical Corps personnel) were used in the study.

The amount of load carried has not always been the single focus of load carriage studies. Goldman and Iampietro (1962) examined the relationship between load, walking speed and grade by expanding on the work of Passmore and Durnin (1955) and Bobbert (1960), who examined energy expenditure while walking with loads on flat surfaces. Goldman and Iampietro developed an equation for the prediction of energy expenditure while backpacking for varying load weights, speeds and grades.

Since Goldman and Iampietro's study several other authors have developed models for predicting the energy cost of walking with loads (Durnin and Passmore 1967, Givoni and Goldman 1971 and Pandolf et al. 1977). However, some time later, Duggan and Haisman (1992) showed that Pandolf et al.'s empirical model for predicting the metabolic cost of walking with loads provided the most valid results when compared with the results of a number of loaded and unloaded walking trials.

The model proposed by Pandolf et al. (1977) is:

$$M = 1.5W + 2.0(W + L)(L / W)^2 + \eta(W + L)(1.5V^2 + 0.35VG)$$

Where:

- M = metabolic rate (watts)
- W = subject weight (kg)
- L = external load (kg)
- $\eta$  = terrain factor ( $\eta = 1.0$  for treadmill)
- V = velocity
- G = grade, slope (%)

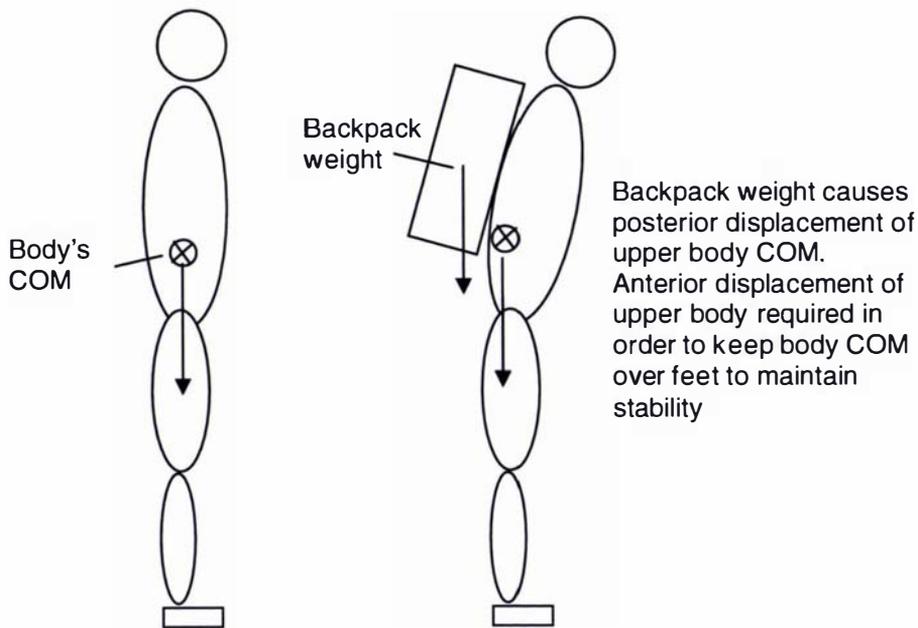
From Pandolf et al.'s model it becomes obvious that there are many variables in addition to load that can affect energy expenditure during load carriage. A limitation to Pandolf's model was pointed out by Myles and Saunders (1979) who studied cardiopulmonary responses ( $VO_2$  and HR) to treadmill walking with loads weighing

10 and 40% BW. Although oxygen consumption was standardised across the two load conditions (treadmill was adjusted so that the equivalent to 35%  $\text{VO}_2$  max was achieved using Pandolf's model), the heavier load resulted in higher cardiopulmonary and rate of perceived exertion measures (RPE). The results suggest that oxygen consumption is not a full representation of the physical strain of backpacking, as for the same oxygen consumption, the heavier load was perceived as harder work. This may also be true for changes in carriage duration or distance and specific backpack attributes such as adjustment or design.

## A basic model of backpacking

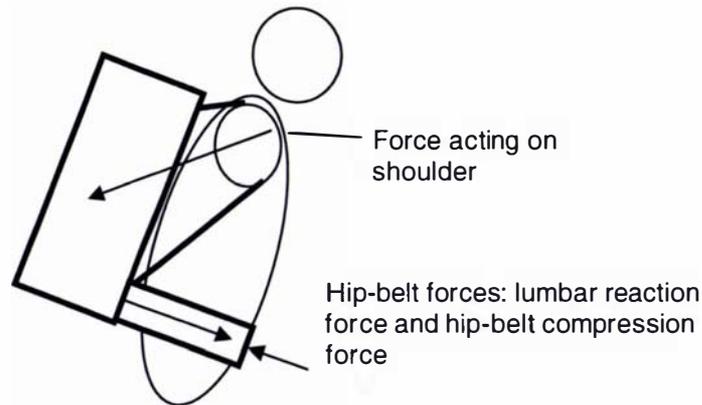
A number of studies have demonstrated a biomechanical model of the forces involved when backpacking (Bobert and Norman 1984, Bryant et al. 1996 and Milanese 1999). Carrying a backpack on two shoulders creates a posterior shift in the body's centre of mass (COM) (figure 1), which requires an anterior shift in the person's upper body in order for the body's centre of mass to remain over the feet and therefore maintain stability.

**Figure 1.** Shift in a person's centre of mass position when a backpack is worn, and the resultant upper body shift that must take place in order to maintain stability.



Usually shoulder straps and a hip-belt are used to secure the backpack on the person's back. The major forces affecting the upper body can be seen in figure 2. If a hip-belt is worn, much of the shoulder force can be reduced as the weight of the backpack is largely being born by the resistance of the hip-belt on the hips and the lower backpack on the lumbar region. However, in order to provide this hip-belt resistance, the tightened hip-belt also provides a compressive force on the lower abdominal region. The erector spinae and abdominals, have been identified as the major trunk muscles responsible for stabilising the backpack weight, while the shoulder protractors – serratus anterior, pectoralis major and pectoralis minor, and elevators – upper trapezius, levator scapulae and rhomboids have been identified as the muscles that resist the shoulder strap forces (Bobert and Norman 1984, Milanese 1999).

**Figure 2.** The major forces acting on the body as a result of backpacking



## Backpack weight, distance carried and walking speed

Many studies have examined physiological and biomechanical responses to backpack weight, distance carried and walking speed in realistic situations. Often the objective has been to determine an upper limit for backpack load weight (Shoenfeld et al. 1977, Borghols 1978, Shoenfeld et al. 1978, Soule et al. 1978, Myles and Saunders 1979, Cymerman et al. 1981, Kinoshita 1985, Martin and Nelson 1986, Epstein 1987, Charteris 1998).

Shoenfeld et al. (1977) used physiological and questionnaire measures to determine the maximal backpack load that could be carried by 32 young men on a 20 km march on a paved surface. The participants were divided into three groups who carried 20, 25 and 30 kg in identical backpacks. All groups marched at 5-6 km/hr. Carrying 30 kg caused a significant drop in maximum oxygen consumption following the march, whereas carrying 20 and 25 kg had no effect. Carrying 30 kg also caused more complaints regarding difficulties in performing the test. Based on these results, 25 kg (approximately 38% BW) was reported as the maximal load weight that could be reasonably carried for the conditions.

Focussing on slightly shorter distances, Shoenfeld et al. (1978) studied the effects of carrying 30 kg (approximately 44% BW) and 35 kg (approximately 51% BW) for 6 km and 12 km on physiological measures for 20 young men. Based on significant changes in mean heart rate, oxygen consumption and blood glucose, 30 kg was found to be an “optimal” load for 12 km and 35 kg was found to be optimal for 6

km. More conservatively, Pierrynowski et al. (1981) suggested that for the military, between 18 kg (approximately 25% BW) and 28 kg (approximately 39% BW) would be an acceptable backpack load if the carrier was to arrive at their destination in an unfatigued state. However, due to a culture of acceptance of physical discomfort in the military, it is likely that greater loads would be deemed acceptable in military, than in civilian load carriage.

A comprehensive review of civilian and military studies concerned with loads carried on the trunk, hands or head was conducted by Haisman (1988). The review concluded that the energy cost of walking with loads has been found to depend primarily on walking speed, body weight and load weight, together with terrain factors such as gradient and surface type. In addition the review reaffirmed that there is no obvious definition of a maximal load, due to the varying circumstances in which loads are carried. However, there seemed to be a consensus that as a general rule of thumb, one third of body weight (or the load that produces one third of maximal oxygen consumption for a working day) is a maximum load for average sized, healthy young males.

A more recent review has been carried out by Knapik (1996) who focussed on the physiological, biomechanical and medical aspects of backpacking. Knapik's review demonstrated that load carriage can be facilitated by reducing total loads, modifying equipment, improving load distribution, improving physical training and using specific techniques to prevent injury. These concepts would logically also apply to schoolbag carriage. More recently, Knapik (2004) repeats these assertions but highlights some of the issues specific to military load carriage. For example, the benefits of load placement on the back may depend of whether soldiers are marching for long durations on even terrain (high placement may be better) or are moving over uneven terrain (lower placement may be better).

Some researchers have favoured a kinematic approach to the study of backpacking (Kinoshita 1985, Martin and Nelson 1986, Charteris 1998). Kinematic analyses of load carriage allow the study of whole body movement and the movement of individual body segments in response to carrying external loads. More specifically,

gait patterns and postural changes have been used to indicate the effects of varying load carrying conditions.

The kinematic and kinetic effects of carrying 20 and 40% BW on the back and both on the front and back (double pack) was investigated by Kinoshita (1985). Not surprisingly, it was found that carrying any load changed the kinematic patterns of gait and that the double support phase increased and the single support phase decreased with increasing weight. Also, increased trunk flexion was observed when the backpack was worn compared with the double pack.

In a similar study to Kinoshita, Martin and Nelson (1986) studied the effect of carried loads on the walking patterns of men and women. Standardised loads of 9, 17, 29 and 36 kg were carried in the arms (two lightest loads) and in backpacks (two heaviest loads) while walking at  $1.78 \text{ m}\cdot\text{s}^{-1}$ . The results were similar to those found by Kinoshita, with double support time and stride rate increasing with load and stride length and swing time decreasing with load. Martin and Nelson unexpectedly found that female's gait kinematics was more affected by increasing load than their male counterparts. This phenomenon should not be too surprising as females are generally smaller than males and thus would carry a higher proportion of their body weight if the weight were standardised. Martin and Nelson finally pointed out that their study was conducted under unfatigued conditions and therefore the effects of fatigue on the kinematics of load carrying would make valuable future research.

More recently, Charteris (1998) studied the effects of backpack loading on floor contact patterns by the foot using footswitches. Forty-five young adult males carried 20, 30, 40, 50 and 60% BW loads in a backpack along a 40 m walkway. Again it was found that increasing load caused an increase in the double support phase of gait, generally causing a wider base of support and therefore greater stability. However, in this instance the differences from the unloaded condition were not great. Other kinematic measures such as cadence were not affected until the load reached 50% BW.

Cumulatively, most kinematic backpacking studies suggest that backpacking causes a decreased swing phase, increased double support phase and an increase in trunk flexion. LaFiandra et al. (2003) reported a more comprehensive description of trunk co-ordination and stride parameters as a result of backpacking with 0 and 40% BW while walking 0.6 and 1.6 m.s<sup>-1</sup>. Increases in walking speed were shown to result in increased pelvic rotation in order to increase stride length in unloaded walking. Load carriage caused decreased pelvic rotation, which was compensated for by increased hip excursion. However, increased hip range of motion was not enough to compensate for the reduced hip rotation and therefore stride length decreased and stride frequency increased.

In summary, adult load carriage studies suggest that between 30-40% of BW is a maximum acceptable load in military situations. This is substantially higher than the currently recommended 10% BW (the origins of this recommended limit will be discussed later in this review) for schoolbag carriage. The difference might partly be explained by the immature musculoskeletal development of school students (which will be discussed in the next section) and above average load carriage specific fitness of military personnel, although no studies have addressed this.

The adult literature also shows that upper load carriage limits depend on distance of carriage and that walking speed affects gait kinematics. Although students' responses to schoolbag carriage might differ in pattern and magnitude, they would also be dependent on walking distance and speed and therefore need to be considered in schoolbag carriage recommendations.

## **Backpack adjustment**

Apart from backpack weight, distance carried and walking speed, the physical demands of carrying loads may be further affected by manipulating the adjustment or 'fit' of a backpack. Bygrave et al. (2000) compared backpacking with loose and tight shoulder straps. Wearing a backpack (15 kg) with tight straps resulted in decreased expired air in the first second of expiration (FEV<sub>1</sub>). This finding suggests that the tightness of fit of a backpack might restrict a person's ability to breathe, which may in turn affect performance. Decreased (FEV<sub>1</sub>) and forced vital capacity

(FVC) have also been demonstrated in school students when schoolbag carriage reached 20% BW and also when the students assumed a kyphotic posture (Lai and Jones 2001). The mechanism for this may be similar to that shown by Bygrave et al. (2000) in that the normal mechanics of breathing may be restricted by forces from the backpack.

Positioning the load in a backpack near the mid-back rather than just above shoulder level has been shown to decrease erector spinae and upper trapezius muscle activity (Bobet and Norman 1984). In this case, a more stable load position with less moment of inertia was given as the cause of the lower EMG activity for the lower load placement position. Although not mentioned by the authors, a possible confounding factor might have been the contribution of the hip-belt for the different load positions. If the entire backpack was positioned higher for the high load position, then the support offered by the hip-belt would differ than when the backpack was positioned lower on the back. In addition, only the erector spinae and upper trapezius muscle activity was measured. It may be possible that shifting the load position, created increased activity in muscles that were not measured in this study. However, given the mechanics of backpacking, it appears reasonable that the upper trapezius and erector spinae muscles could be considered the primary muscles responsible for resisting a backpack load.

In a study involving school students (Grimmer et al. 2002), postural adjustment to backpack load was greater when it was carried high on the back. Grimmer et al. suggested that this might be due to the centre of mass of the load being further posterior to the body centre of mass when the load is carried higher on the back. This would mean that the person must lean further forwards in order to bring the backpack / body centre of mass over the feet for stability. These results support the findings of Bobet and Norman (1984), where a lower backpack position also resulted in 40% less dynamic moment. However, these findings are to some degree confounded by Bloom and Woodhull-McNeal (1987) who suggest that a lower load position requires greater forward body rotation in order to maintain stability. In addition, Stuempfle et al. (2004) showed that  $VO_2$ , VE and RPE were all significantly lower when a backpack load was placed higher on the back, when

walking on a level treadmill, and suggested that this might be the most energy efficient load position.

A vertically arranged backpack load, using slanting partitions within the main compartment, was found to result in significantly less shoulder, neck, lower back and overall perceived discomfort (Jacobson et al. 2003). It was proposed that the slanting partition system would prevent the majority of the contents resting at the bottom of the backpack. The results support the view that a vertically arranged load would result in less torque on the shoulders due to the load centre of mass being horizontally closer to the person's centre of mass. This should also be the case for school students, although it has never been examined.

The most appropriate position for a backpack load appears to depend on the measures that are used to compare conditions. Because previous studies have used varying methodologies to compare backpack adjustments, there is not yet conclusive evidence to suggest optimal backpack adjustment criteria. Also, the effects of other areas of backpack adjustment such as hip-belt tension or placement have often not been considered, although it has been demonstrated that pressure on the skin may limit load carriage if a hip-belt is not worn (Holewijn 1990). However, what is clearer is that backpack adjustment has implications for the physical demands placed on the user. This must also be true for schoolbag carriage and should be considered when attempting to determine students' responses to schoolbag carriage.

## Backpack design

The effectiveness of different backpack designs has been reported in adult load carriage literature, but not in schoolbag carriage literature. The adult backpack design findings may have useful implications for the assessment of schoolbag design.

Whole body postural adjustments were studied by Bloom and Woodhull-McNeal (1987) in order to compare an external and internal frame backpack, weighing 19 kg for seven male participants and 14 kg for nine female participants. Participants leaned further forward while wearing an internal frame backpack, probably because

the load was positioned lower, requiring the user to lean further forward to maintain equilibrium of their centre of mass. In addition it was found that most of the forward lean occurred through hip flexion and head protraction. However, it was acknowledged by the authors that the centre of volume of the internal-frame backpack was lower and closer to the body, which suggests that the results were a result of centre of mass changes which followed different backpack designs.

However, Kirk and Schneider (1992) reported that no differences in metabolic, cardiorespiratory or perceptual responses were shown between internal and external framed backpacks. This is not surprising given the subtle local muscular differences or gait compensations that would result from two different but similar backpack designs. It was noted that the differences in design may not have been great enough to evoke differences between the conditions and that the effects of padding and fit on general comfort might be detectable. Differently from Bloom and Woodhull-McNeal (1987), the authors reported that the internal framed backpack had a centre of mass that was closer to the back of the wearer than the external framed backpack. Nevertheless, the main effect of the different backpack designs would have been a shift in the backpack's centre of mass position.

The effectiveness of a double-pack design where part of the load is carried on the front of the torso has been evaluated (Kinoshita 1985, Cook and Neumann 1987, Lloyd and Cooke 2000). Double-pack carriage resulted in body posture and gait patterns being nearer to unloaded walking than conventional backpacking (Kinoshita 1985). In addition, Lloyd and Cook (2000) reported shorter support time and greater propulsive forces when a double-pack was used compared with a standard backpack. However, Cook and Neumann (1987) showed that using a double-pack caused greater paraspinal muscle activity, which may lead to earlier fatigue. Cook and Neumann qualified their results by noting that the relative importance of paraspinal muscle activity in load carriage is difficult to estimate.

Some of the most recent backpack research has shifted focus, from empirical biomechanical or physiological studies of the physical demands of backpacking, to more applied studies that seek to develop testing protocols for backpack design

(Holewijn and Lotens 1992, Legg et al. 1997, Rigby et al. 1998, Bryant et al. 2001, Jones and Hooper 2003, Reid et al. 2004, Stevenson et al. 2004a, 2004b).

In order to test the effectiveness of 10 different backpack designs for military purposes, Holewijn and Lotens (1992) opted for a test battery that included a vertical jump, crawling underneath wires for 10 metres, stepping stones and a number of other tasks that might be encountered in military situations. Participant's test battery scores and their subjective responses to a questionnaire were used to compare backpack designs. The backpack designs incorporated variations of weight, position of centre of gravity, volume, volume distribution and motion restriction of the shoulders.

A regression model was developed, explaining 78% of the variance in the data:

$$LP = 1.07 * W + 0.2 * V$$

Where LP = Loss of performance (% - based on test battery performance)

W = increase in weight (kg)

V = increase in volume (L)

Load weight and volume were therefore found to have the greater effect on performance, while shoulder motion restriction and volume distribution had no significant effect. However, the test battery results may not have been sensitive enough to detect the more subtle changes in backpack design.

The possible lack of sensitivity of physiological and biomechanical measures when comparing backpack designs was pointed out by Legg et al. (1997) who used a Category Ratio Scale (CRS) and written questionnaires to compare two designs of leisure backpack before and after a 30-minute walk. The CRS ratings were ineffective in comparing the backpacks, but the written questionnaires provided sufficient detail to enable an effective comparison. This suggests that subjective opinions of participants might be an effective tool for the analysis of backpacks and may be used in testing protocols for the development of backpack designs. More

recently, Legg et al. (2003) found that qualitative subjective perceptual methods were more effective than quantitative perceptual methods in comparing the design features of different backpacks under field conditions. Free-format written responses to semi-structured open-ended questions provided specific reasons for participant's preferences of two backpacks after a 15-minute 1313m walk. Conversely, participants' responses to written post-field trial questions on visual analogue or category ratio rating scales were unsuccessful in distinguishing between backpacks.

In Canada, a suite of objective biomechanical measurement tools for backpack assessment has been developed (Stevenson et al. 2004a), including a mechanical load carriage simulator. Skin contact pressures, strap forces and relative displacement of a backpack with respect to a mannequin on the simulator were compared with subjective evaluations of the same backpack following field trials (Bryant et al. 2001). Good predictive agreement was found between the two measurement systems suggesting that the load carriage simulator is a useful tool in developing backpack design. Conversely, it also supports the view that subjective perceptual methods can provide similar (and possibly cheaper) information to the more technically complex (and possibly more expensive) methods. Unlike the findings of Holewijn and Lotens (1992), backpack stiffness (and therefore shoulder restriction) was found to be inversely proportional to performance in an agility test. Caution should be exercised when interpreting the simulator results as there is no published data which validates the load carriage simulator in terms of its ability to reproduce realistic backpack load carriage movement. However, the authors rightly point out that the simulator has been shown to predict subjective results from field trials and is designed for this purpose, rather than to reproduce realistic movement.

The Canadian load carriage simulator has been used in the development of a Canadian military backpack along with human trials (Stevenson et al. 2004b). It was found that the simulator added to the design process by quantifying design changes, predicting soldier's responses to design changes, objectively comparing different backpack designs and providing rapid feedback between design iterations. Rods positioned on the lateral borders of a backpack, with the purpose of transferring force from the upper torso to the hips, have also been evaluated using the load

carriage simulator (Reid et al. 2004). It was found that the rods caused 14% of the vertical load from the upper torso to be shifted to the pelvic region. In addition, the rods provided a mean increase of 12% in the extensor moment at the L3-L4 level which may assist in reducing the demands on the back extensor muscles.

In conclusion, recent studies of backpack design testing suggest that subjective perceptions, performance testing and more sophisticated kinematic and kinetic analyses are the most appropriate tools for comparing backpack performance. Despite differences between adult and adolescent load carriage, similar methods could be used to evaluate load carriage systems for school students. Well designed school bags based on appropriate design evaluations might be a way of controlling detrimental schoolbag carriage forces.

In summary, adult load carriage literature clearly demonstrates that backpack weight, distance carried, walking speed, backpack adjustment and backpack design all affect the users' responses to load carriage. Despite the fact that approximately one third of BW has been reported as an appropriate backpack weight limit for average sized, physically fit, young military males, a single recommended weight limit might be inappropriate when other aspects of load carriage are prone to change. The most appropriate methodology for determining a person's response to load carriage appears to depend on the specific aspect of the load carriage that is being investigated. For studying responses to different backpack weights, physiological and biomechanical measures have been shown to be appropriate. However, for more subtle backpack changes such as backpack adjustment and design, postural and subjective perceptual measures appear to be more effective.

### **3. The physical capabilities of school children**

Early studies of adolescents' physical characteristics are mostly related to growth in height and weight (Count 1943, Frisch and Revelle 1969, Tanner et al. 1976). This information is useful in that the age of adolescent growth spurts have been identified. In a review of published studies of the growth of American boys and

girls, Abbassi (1998) reported that peak height velocity (growth rate) occurs at 13.5 years for boys and 11.5 years for girls.

Many studies of risk factors associated with MSD in school children have involved participants of between 11-14 years as this age of rapid growth is when adolescents appear to be vulnerable to developing MSD. Dalton (1992) explains that adolescents are more susceptible to musculoskeletal injury due to growth cartilage being present at epiphyseal plates, joint surfaces and apiphyses. These can be put under increased strain due to relative tightness across joints as a result of growth spurts. This age is also when school children are carrying the heaviest schoolbag loads relative to their body mass (Grimmer et al. 1999, Whitfield et al. 2001), which may be putting them at further risk of developing MSD.

Body mass (Gilliam et al. 1979, Docherty 1991, Mameletzi 2003) and muscle cross-sectional area (Davies 1985, Ryushi et al. 1988, Kanehisa et al. 1995) have been shown to be highly correlated with muscle strength. In a review of isokinetic muscle strength during growth and maturation (De Ste Croix et al. 2003), it was noted that once stature and body mass are accounted for, maturation is a non-significant contributory factor to muscle strength.

If weight, height and muscle cross-sectional area are good indicators of muscle strength, then comparisons between the physical capabilities of adults and adolescents can be easily made. For example, if an adult male weighed 75 kg and a 13 year old male weighed 55 kg, then it could be argued that the 13-year old has 73% of the strength of the adult. If the maximum recommended weight for adult load carriage in the military (approximately one third BW as reported earlier) is used, then the maximum recommended load for the 55 kg 13-year old can be calculated as being approximately 18 kg. A more conservative approach might be to apply the 73% strength of the 13 year old to the adult limit. This would give a maximum load weight of 14 kg or 25% BW for the adolescent.

In the first example physical capability and muscular strength are assumed to be analogous. The reality might be that although a 55 kg 13-year old is able to carry

one third of BW (18 kg), they might not be able to maintain carrying the load without injury as a result of their immature musculoskeletal system. Even the more conservative limit of 25% BW (14 kg), which might account for the added expectations of military load carriage, is much higher than the currently recommended 10% BW. There is currently no literature that addresses this difference. Therefore, studies that specifically address students' schoolbag carriage must be reviewed in order to gain an appreciation of the health risk it poses and how students respond to schoolbag carriage.

## **4. School bag carriage and reported MSD**

A mechanism for the link between backpacking and MSD has been described (Harman et al. 1992, Knapik 1996, Grimmer and Williams 2000, Orloff and Rapp 2004). The anterior displacement of the trunk that is required to counterbalance a posteriorly positioned backpack, along with the increased force resulting from the backpack load, creates increased activity in the muscles that control trunk posture, which can lead to stressing and consequent microtrauma of ligaments or muscles of the back following repetitive loading (Harman et al. 1992, Knapik 1996, Orloff and Rapp 2004). Uneven loading of the lumbar and cervical intervertebral discs which may not be correctly aligned due to a backpack load may also result in MSD (Grimmer and Williams 2000, Harman et al. 1992). Adams and Hutton (1983), clearly showed that lumbar flexion can result in disc fluid loss. Damage to disc endplates can cause dehydration of the nucleus pulposus and subsequent damage to the annulus fibrosis tissue on the outside of the disc (Lipson and Muir 1981, Osti et al. 1990). An alternative mechanism of injury might be that vertebra that are not correctly aligned through anterior head / neck or whole trunk displacement causes pressure on spinal nerve roots (Davis and Jorgensen 2005). Because the supportive structures of the back are innervated by nocicepters, injury to these areas results in MSD. “Backpack palsy” is specific to the shoulder strap pressure that is caused through the backpacking of heavy loads (Bessen et al. 1987, Sutton 1976, Wilson 1987). The shoulder straps of a backpack may cause traction of the 5<sup>th</sup> and 6<sup>th</sup> cervical nerve roots of the upper brachial plexus, causing numbness, paralysis and minor pain of the shoulder girdle (Knapik et al. 1996). The forces affecting the

backpack wearer may be of particular consequence as it has been shown that some peak joint forces increase disproportionately with backpack load (Goh et al. 1998).

The adolescent spine may be less able to withstand external forces than the adult spine as spinal growth is not completed until approximately 24 years of age (Grimmer and Williams 2000). In addition adolescence is a time of relative inflexibility due to the growth differences of bone and soft tissue (Micheli 1983). Therefore, it may be that adolescents are more vulnerable to backpack related injuries than adults. It may also mean that the mechanism for backpacking injuries in adolescents is different from adults. However, there are currently no studies that have examined these possible differences.

High incidences of MSD have been reported amongst school students (Troussier et al. 1994, Balague et al. 1995, Salminen 1995, Burton et al. 1996, Watson et al. 2002). In a questionnaire study of 615 12-17 year old school students (Balague et al. 1995), 24% of respondents reported a disabling episode of low back pain within the last month. Similarly, Watson et al. (2002) reported a 1-month prevalence of low back pain of 24% in 1446 11-14 year old English school students. Troussier et al. (1994) reported that 26.2% of 1178 participants (6-20 years) experienced back pain on several occasions and 13.2% experienced back pain frequently. Apart from the immediate effects of MSD, there is a concern that MSD experienced in early life may extend into adulthood (Harreby et al. 1995, Leboeuf and Ohm Kyvik 1998) although this is speculative due to a lack of longitudinal studies in this area.

The high prevalence of MSD in young people, along with a suspicion that MSD early in life might increase the risk of similar problems in adulthood, has prompted researchers to attempt to identify the risk factors associated with MSD in schoolchildren (Grimmer and Williams 2000, Jones et al. 2003, Grimes and Legg 2004, Trevelyan and Legg 2004). Age (Salminen 1984, Burton et al. 1996, Grimmer and Williams 2000), gender (Salminen 1984, Troussier et al. 1994, Watson et al. 2002), sporting involvement (Troussier et al. 1994, Burton et al. 1996, Grimmer and Williams 2000), sitting position (Balague et al. 1988, Troussier et al. 1994, Viry et al. 1999) and watching television (Balague et al. 1988, Balague et al. 1994,

Troussier et al. 1994) have all been identified as risk factors associated with reported MSD in schoolchildren. There is a lack of agreement between studies as to which factors are statistically related to reported MSD, although more recently some studies have shown that psychosocial factors are positively associated with MSD (Balague et al. 1995, Jones et al. 2003, Van Gent et al. 2003).

The association between schoolbag weight and MSD has also been studied. This relationship is not clear, as an approximately equal number of studies have found an association (Negrini et al. 1998, Viry et al. 1999, Grimmer and Williams 2000, Sheir-Neiss et al. 2003, Korovessis et al. 2004, Siambanes et al. 2004) and failed to find an association (Goodgold et al. 2002, Negrini and Carabalona 2002, Jones et al. 2003, van Gent et al. 2003) between schoolbag weight and reported MSD. However, of the studies that failed to find any association between schoolbag weight and reported MSD, cumulative exposure has been associated with reported MSD (Negrini and Carabalona 2002, Jones et al. 2003) and heavier backpack loads have been perceived as demanding by students (Goodgold 2002, Negrini and Carabalona 2002, Van Gent et al. 2003).

### **Studies that failed to demonstrate an association between schoolbag weight and reported MSD**

In a prospective population-based cohort study of 1046 11-14 year old school students from Northwest England, Jones et al. (2003) found no relationship between schoolbag weight (median 9.9% of body weight (BW) interquartile range: 7.4%-12.9%) and reported low back pain (LBP). However, although not statistically significant, students who walked to school (and therefore had a greater cumulative exposure to schoolbag load) showed a greater risk of 'new-onset LBP'. Psychosocial factors such as the presence of anger, disobedience and violence (conduct problems) (relative risk: 2.5) and to a lesser extent high levels of hyperactivity (relative risk: 1.4) were found to be the risk factors most highly related to reported LBP.

Negrini and Carabalona (2002) studied reported back pain in 237 school students (mean (SD) age 11.6 (0.34) years). No association between schoolbag weight (mean load 9.3 kg, range 4.4-12.5 kg) and reported back pain was shown. Conversely, time

spent carrying their backpacks ( $p < 0.05$  for life prevalence) and fatigue during schoolbag carriage ( $p < 0.05$  for point and life prevalence) by students was associated with back pain. This finding is similar to that reported by Jones et al. (2003).

Van Gent et al. (2003) also failed to find an association between schoolbag weight (mean 14.7% BW, range 5.5%-29.2%) and reported neck, shoulder or back pain in their study involving 745 12-14 year old school students in the Netherlands. Although not reported as a statistically relevant finding, a p-value of 0.062 was found in an analysis of variance (ANOVA) for the percentage of school students who carried less than 10% BW reporting neck/shoulder complaints, compared with those who carried between 10% and 18% BW. Although an alpha level of 0.05 was set for the analysis of variance, a p-value of 0.062 could be considered 'marginally significant' and increases in the sample size or measurement precision may have resulted in this comparison being statistically significant. However, the variance of the data was not given in this study, so it is impossible to determine the effects of increasing sample size on the resulting p-value. Van Gent et al. (2003) also showed that perceived weight of the schoolbag was associated with a greater percentage of school children with neck/shoulder ( $p = 0.04$ ) and back ( $p = 0.05$ ) complaints.

Goodgold et al. (2002) found no association between reported back pain and schoolbag weight (mean (SD) girls 18.2% (8.3%) BW, boys 16.6% (7.5%) BW) in their study of 345, 11-14 year old school students. However, 74% of students carrying loads of 15% BW more frequently reported that their bag was 'heavy' compared with students carrying lighter loads. These findings are consistent with studies that have failed to demonstrate a schoolbag weight / MSD association in that schoolbags are commonly perceived as a considerable burden by school students. Van Gent et al. (2003) calculated that only 39.7% of their school students reported their schoolbag as 'no problem' and Negrini and Carabalona (2002) showed that schoolbags were perceived to be heavy by 79.1% of school students, to cause fatigue by 65.7% and to cause back pain by 46.1%.

More recently, 176 school students (11-14 years of age) completed a questionnaire relating to their medical history, in and out of school activity, school bag type and

reported neck, shoulder and back pain (Pucktree et al. 2004). Interestingly, although there was no statistical relationship between schoolbag weight and reported pain, more reported pain was associated with wearing a double strapped backpack, than for a single strapped bag ( $p < 0.001$ ). However, the mean backpack weight for the group was less than 10% BW. Such relatively low schoolbag weights would be less likely to invoke pain responses than the heavier loads that have been reported in previous studies.

In a descriptive analysis of injuries relating to visits to emergency departments throughout the United States, Wiersema et al. (2003) found that 89% of backpack injuries did not involve the back. Only 6% of back injuries were related to wearing a backpack and the most common site of injury as a result of wearing a backpack was the head/face. The most common mechanism for backpack injuries was tripping over a backpack and being hit by a backpack. Although Wiersema et al. point out that backpack safety initiatives should be expanded to cover tripping over and being struck by a backpack, the findings do not consider the more likely long-term / overuse backpack injury mechanism. The long-term development of injury that is likely to be associated with backpack use, would generally not be associated with visits to emergency departments and therefore have not been considered in this study.

Although these studies failed to show a direct association between schoolbag weight and reported MSD, the total exposure to schoolbag carrying and school students' perception of schoolbag weight appear to be areas of concern. Furthermore, in most cases authors have acknowledged that there may be reasons for the absence of an association between schoolbag weight and reported MSD. School students may carry lighter loads after experiencing an episode of MSD, which might confound results. Also, the complicated nature of MSD might mean that multiple risk factors contribute to the eventual experience of pain (Brackley and Stevenson 2004). For example, a school student carrying a heavy schoolbag might not be susceptible to MSD unless other risk factors such as gender, sporting involvement, psychosocial factors, mismatch between school furniture and student body size and total duration and mode of schoolbag carriage are included. These kinds of complicated

interactions, which may explain the development of MSD in some school students, have not been examined in previous studies.

## **Studies that demonstrate a positive association between schoolbag weight and MSD**

Some studies have reported a positive association between schoolbag weight, along with other schoolbag factors and reported MSD. In a South Australian study of 1269, 12-18 year old school students, Grimmer and Williams (2000) found an association between schoolbag weight (mean (SD) 9.1(3.6)% BW) and reported LBP and an even stronger positive association between schoolbag carriage duration and reported LBP. The results also differed for boys and girls, with boys showing a stronger relationship between schoolbag weight and reported LBP in the earlier years (odds ratios 1.9-8.6 when greater than 6% BW carried for year 8 students). It was suggested that the different growth stages of boys and girls in the study might have caused this difference. It was also mentioned that this would be difficult to control within the sample.

A significant association ( $p < 0.01$ ) between non-specific back pain in the previous year and schoolbag carriage of greater than 20% BW in 12, 14 year old school students was observed in a cross-sectional study by Viry et al. (1999). Schoolbag carriage by hand and walking to school was also associated with higher reporting of non-specific back pain ( $p < 0.01$ ). Only 123 students participated in Viry's study which may mean that the findings should be interpreted with caution. If the following equation is used to determine power:  $N = 32/ES^2$  (Hopkins 2001), and the smallest worthwhile difference in relative schoolbag weight was 2% of BW, with the overall standard deviation of 6.8% BW that was reported by Viry et al, a sample size of 372 participants would be required to obtain sufficient power. However, the extremely heavy loads the participants were carrying (mean (SD) 19.3 (6.8)% BW), might have meant that students' reported back pain was more likely than that reported by Grimmer and Williams (2000), where the mean schoolbag weight was only 9.1% BW.

Schoolbag weight (odds ratio 1.98,  $p < 0.0001$ , median, 14.4%; range: 1-41% BW) and duration of carriage were found to be associated with higher incidences of reported back pain in 1126, 12-18 year old school students from 12 schools in North America (Sheir-Neiss et al. 2003). This cross-sectional study utilised the first phase of a longitudinal study for its data. Future results from this study will be able to add considerable strength to the literature, as it will be the first longitudinal study to examine the association between backpack weight and MSD. Sheir-Neiss's results are similar to Viry et al. (1999) and Grimmer and Williams (2000) in that both schoolbag weight and carriage duration were associated with MSD.

In a recent cross-sectional study of 3,498 students (11-15 years) in California (Siambanes et al. 2004) it was found that backpack weight was effective in predicting back pain ( $p < 0.01$ ). In addition, girls and those who walk to and from school were also more likely to report back pain ( $p < 0.01$ ). The mode of carriage, socioeconomic status and age were not found to be significantly related to the prevalence of back pain.

In another large scale cross-sectional study (Korovessis et al. 2004), 3441 school students (9-15 years) were asked about their dorsal pain (DP) and LBP within school time while carrying their backpack. Backpack weight and spinal curvature were also measured directly. Dorsal pain was found to increase with increasing backpack weight ( $p < 0.05$ ) while the mode of carriage (one vs both shoulders) had no effect on DP or LBP. Also, while girls experienced more DP than boys ( $p < 0.001$ ), age, height, weight and spinal curvature (kyphosis, lordosis and scoliosis) did not correlate with either LBP or DP. All of these findings are similar to those reported by Siambanes et al. (2004).

No relationship between schoolbag weight and reported musculoskeletal symptoms for a group of third form (mean (SD) 13.6 (1.3) years) and sixth form (mean (SD) 17.1 (0.6) years) school students was found in a cross-sectional study by Whittfield et al. (2004). However, there was a positive association between schoolbag weight and reported upper back pain for the third form group only, who were also carrying the heaviest schoolbags (13.2 (4.7)% BW). Conversely, the sixth form group, who

carried less schoolbag weight, demonstrated higher levels of reported low back pain. Whittfield's results are somewhat different to those reported by Siambanes et al. (2004) and Korovessis et al. (2004) in that there was a difference in reported pain by different age groups.

In summary, most of the studies that have shown a positive relationship between schoolbag weight and reported MSD have also shown a relationship between schoolbag carriage duration and back pain. All of the studies that have examined schoolbag carriage duration or exposure, including those that failed to demonstrate an association between schoolbag weight and reported MSD, have shown an association with reported MSD. This indicates that the temporal patterns of schoolbag carriage should be more thoroughly investigated so that it can be considered in the development of evidence based schoolbag carriage guidelines. In addition, other factors such as schoolbag design, adjustment and schoolbag donning and doffing may also affect students' susceptibility to MSD. These areas have not been addressed in the literature and warrant investigation.

## **5. Student responses to Schoolbag carriage**

It has been demonstrated that some aspects of schoolbag carriage are among the risk factors contributing to reported MSD in school students. Prompted by this relationship, an increasing number of studies have examined students' biomechanical or physiological responses to schoolbag carriage, in order to better understand the mechanisms that might lead to MSD. More specifically, some studies have attempted to obtain evidence to identify a maximum schoolbag carriage limit.

Maholtra and Sen Gupta (1965) studied the energy cost and heart rate of six male school students aged between 9 and 15 years as a result of carrying schoolbags (2.7 kg) in different positions, while walking on a treadmill at 2.5 mph. Hand carrying was found to be consistently more demanding (mean HR 119 bpm) than two shouldered backpacking (mean HR 100 bpm) and it was stated that students were not likely to carry more than 10-12% of their body weight, although there was no data to support this assumption.

## Chapter 6 - Schoolbag weight: A psychophysical approach

### Appendix 16. Raw data

Raw data for maximum acceptable schoolbag weight using psychophysical approach

Participant	Height	Weight	start Low	start High	diff	Mean	%BW
1	143.0	40.2	4.6	4.2	0.4	4.4	10.9
2	168.0	57.6	7.3	7.1	0.2	7.2	12.5
3	184.5	103.1	5.4	4.2	1.2	4.8	4.7
4	158.0	58.3	4.2	5.8	1.6	5.0	8.6
5	159.0	47.3	5.6	6.4	0.8	6.0	12.7
6	175.5	54.9	9.2	9.0	0.2	9.1	16.6
7	144.0	33.5	5.3	5.5	0.2	5.4	16.1
8	157.5	42.8	2.0	1.5	0.5	1.8	4.1
9	159.0	44.3	4.1	3.7	0.4	3.9	8.8
10	169.5	57.4	5.0	6.6	1.6	5.8	10.1
11	167.5	58.8	5.9	5.4	0.5	5.7	9.6
12	166.5	57.8	2.8	2.4	0.4	2.6	4.5
13	151.5	39.3	4.6	4.1	0.5	4.4	11.1
14	163.5	56.8	3.3	8.5	5.2	5.9	10.4
15	140.5	30.4	4.8	4.4	0.4	4.6	15.1
16	166.0	50.4	5.4	5.1	0.3	5.3	10.4
<b>Mean</b>	<b>160.8</b>	<b>52.1</b>	<b>5.0</b>	<b>5.2</b>	<b>0.9</b>	<b>5.1</b>	<b>10.4</b>
<b>Stdev</b>	<b>11.9</b>	<b>16.5</b>	<b>1.7</b>	<b>2.0</b>	<b>1.2</b>	<b>1.7</b>	<b>3.8</b>

In a study of 1522 school students across four classes (Voll and Klimt 1977), school bag weights (11%-14% BW), mode of carriage, distance travelled to school and each students' packing habits were all measured. More than 50% of students reported their schoolbag as being too heavy or quite heavy and the majority wore their schoolbags on their back using both shoulder straps. It was also mentioned that a regional school council recommended that the schoolbag weight should not exceed 11%-13% BW and that a "scientific delegation" considered that schoolbag weight should be less than 11% BW.

School bag weights were measured and compared across four primary school classes by Sander (1979). Although the number of participants and their ages or physical characteristics was not reported, a schoolbag limit of 10% of body weight (based on the advice of an orthopaedic doctor) was often exceeded by the students. The possible adverse effects of carrying loads asymmetrically were also noted.

More recently, increasingly thorough analyses of responses to schoolbag carriage have been undertaken. Pascoe et al. (1997) studied the effects of schoolbag carriage on the static posture and gait kinematics of school students (11-13 years). The physical characteristics, bag weight, carrying method and physical symptoms of 61 school students (mean (standard error) age, weight and height 11.3(0.1), 45.4(1.4) and 1.52(1.8), respectively) were determined. The mean (SD) schoolbag weight for this group was 7.7(0.2) kg (17% of the students' mean body weight). In the second phase of the study, ten of the students that most represented the group mean from a combined ranked score of height, weight, arm width and shoulder width were chosen. The previously determined average school bag weight of 7.7 kg (17% BW) was used as a standard load that was carried by the participants while their self-paced gait was captured, using video, from the front and the side. Head and trunk angles (amount of flexion) were measured from the side views and shoulder elevation and spinal angle (lateral flexion) were measured from the front views.

Pascoe et al. found that the majority of students reported their school bags as "heavy" (65.5%) and a clear majority (92.4%) used backpacks. This was similar to

the findings of Voll and Klimt (1977). One-strap bags promoted more lateral flexion and shoulder elevation than the other carrying methods, while a one strap athletic bag promoted significantly more angular motion of the head and trunk compared with backpacks. Carrying a backpack promoted significantly more flexion of the head and trunk compared to other carrying methods. During gait, bag carrying in general was found to decrease stride length and increase stride frequency, which had the effect of reducing the duration of the support phase. Based on the significant change in posture and high reporting of the load as 'heavy', demonstrated by Pascoe et al., it would seem that 17% BW may be an excessive schoolbag weight. A limitation of Pascoe et al's study is that it was not reported whether walking 'at a self determined pace' was carried out on the ground or on a treadmill. Limitations in measuring gait kinematics during treadmill walking have been observed (Murray et al. 1985, Vogt et al. 2002 and Wass et al. 2005) and may not accurately represent the kinematics of walking over ground.

Preferring to use a physiological approach, Hong et al. (2000) measured the oxygen consumption, heart rate and blood pressure of 15 male primary school students (mean BW  $33.53 \pm 2.64$  kg, height  $141.86 \pm 3.77$  cm) while walking on a treadmill at  $1.1 \text{ m}\cdot\text{s}^{-1}$  and carrying loads of 0, 10, 15 and 20% BW, each for 20-minutes. Each load was randomly assigned to each student over four different testing days. No significant difference in heart rate was detected between all loads carried, but significant differences in blood pressure were detected for loads between 0 and 20% BW and 10 and 20% BW. Energy expenditure was only statistically different between 0 and 20% BW and blood pressure recovery was statistically longer for 15 and 20% BW than for 0% BW.

Hong et al. also recommended 10% BW as a schoolbag weight limit. This recommendation is only partially supported by their data given that there was no difference in heart rate between load conditions and only a difference in energy expenditure between 0% and 20% BW conditions. However, the results clearly suggest that 20% BW is an excessive schoolbag weight based on physiological measures.

In a study in which the experimental design was similar to that of Hong et al. (2000), Hong and Cheung (2003) also compared the effects of school students' load carriage for 0, 10, 15 and 20% BW. In contrast to the findings of Hong et al. (2000), gait patterns and trunk posture were used to detect responses to a more realistic 1892 m walk around a basketball court. No significant differences in posture were observed between the beginning of the walk and near the end of the walk. More positively, significant differences were observed between the 0% BW and the 20% BW schoolbag weights for duration of the stance phase (greater with increased load), duration of second double support phase (greater with increased load), duration of swing phase (less with increased load) and trunk inclination angle (greater with increased load). These findings are in agreement with the increased support phase duration and decreased swing phase duration reported by Pascoe et al. (1997).

Hong and Cheung's results reinforce Hong's findings in that statistically detectable responses to schoolbag carriage did not occur until 20% BW was being carried. Also the results suggest that the effect of load magnitude has a greater effect on gait than does load carriage duration. This differs from the findings in epidemiological studies. However, Hong and Cheung mentioned that perhaps the walking duration was not sufficient to produce gait changes as a result of fatigue. Nevertheless, Hong and Cheung's schoolbag study was the first to recognise within their methodology, that the duration of prolonged load carriage may affect the demands on the carrier.

The effects of Chinese primary school children (9-11 years) carrying schoolbag loads of 10, 20 and 30% BW on lung volumes was studied by Lai and Jones (2001). Forced expiratory volume in the first second ( $FEV_1$ ) and forced vital capacity (FVC) were significantly diminished when schoolbag carriage reached 20% BW and also when the students assumed a kyphotic posture. These results are in agreement with those of Hong et al. (2000) and Hong and Cheung (2003), where 20% BW appears to be a point at which significant physiological and biomechanical responses may be observed. Lai and Jones support the schoolbag weight limit of 10% BW due to the fact that no differences in lung volumes were observed between 0 and 10% BW. However, because nothing was reported regarding loads between 10 and 20% BW, there may be inadequate evidence to support a schoolbag weight limit of 10% BW.

Following on from the postural changes observed by Pascoe et al., the decrease in lung volume as a result of an assumed kyphotic posture observed by Lai and Jones, adds to the rationale for using postural methods in order to study responses to schoolbag carriage.

Using a mixed methodology, Li et al. (2003) studied the effects of carrying 10, 15 and 20% BW on trunk posture and respiratory parameters of 15 Chinese boys (the same participants used by Hong et al., 2000). The authors concluded that a significant increase in trunk forward lean and decrease in trunk range of motion resulted from walking with a load of 20% BW. However, closer examination of the results shows that significant changes in forward lean occurred when 10% BW was carried. In addition, although a significant difference in forward lean between the 10% BW and 20% BW conditions was reported after a 20-minute walk, no significant differences in forward lean for any single load condition occurred after walking for 20-minutes. These results suggest that fatigue alone after a 20-minute walk was not enough to induce changes in forward lean, but a mixture of increased load and fatigue following a 20-minute walk was enough to significantly affect trunk posture. This may mean that students' responses to schoolbag carriage are likely to be affected by schoolbag weight and carriage duration, rather than schoolbag carriage duration alone. Minute ventilation also increased during walking for the 15 and 20% BW conditions. This was due to increased breathing frequency rather than tidal volume. These results are similar, but not the same as Hong et al. (2000), who reported significant increases in oxygen consumption, only after 20% BW was carried.

The effect of backpack weight, age and walking time on dynamic posture (trunk inclination angle and trunk range of motion) has been studied in children (Li and Hong 2004). In this study, 22 boys (two groups:  $6 \pm 0.4$  years and  $12 \pm 0.4$  years) were exposed to backpack loads of 0, 10, 15 and 20% BW, each while walking on a treadmill for 20-minutes. Similarly to Li et al. 2003, the 20-minute walk caused no change in trunk posture for any load condition. However, in the six-year-old group, carrying a load of 15% BW and 20% BW caused a statistically significant change in trunk posture, compared with the unloaded condition, while in the 12-year-old group

all load weights caused a statistically significant change in trunk posture, compared with the unloaded condition. The greater trunk inclination angle demonstrated by the 12-year-old group may have been due to the heavier absolute loads that they were carrying.

Chansirinukor et al. (2001) pointed out that no studies had examined the position of the head on the neck and the neck on the thorax as a result of schoolbag carriage. It was also noted that such analyses were important because of the risk of strain to cervical joints and soft tissue and impaired muscle performance. Consequently, the effects on cervical and shoulder posture of carrying 15% BW in a schoolbag over one shoulder and both shoulders while standing and walking, were examined in 13 school students (mean (SD) age 14.8(1.0) years). The mean schoolbag weight that the sample normally carried was 9.1% BW and ranged between 6.4% BW and 13.2% BW. The authors suggested that because carrying 15% BW statistically affected cervical and shoulder posture (increased forward head position), this weight is too heavy for high school students aged 13 to 16 years and that carrying a load less than 15% BW is recommended.

Increased forward head position was also detected after a five-minute walk, suggesting that duration of carriage and therefore fatigue may also be a variable that can affect posture. Although the fatigue effect is contrary to that reported by Hong and Cheung (2003), it reinforces that aspects of schoolbag carriage other than load weight are also important and need to be considered in future studies.

The association between posture that deviates from gravitational alignment and spinal pain (Grimmer and Williams 2000), prompted Grimmer et al. (2002) to use postural measures to compare schoolbag weights of 3, 5 and 10% BW in 250 Australian adolescents (12-18 years). It was found that the horizontal displacement of body markers increased with increasing load. However, no statistical difference in posture for the three loads was observed. Therefore it was concluded that based on posture there is no evidence for a schoolbag weight limit of 10% BW. Grimmer et al. also studied 'high' and 'low' backpack positions relative to the spine. Contrary to the findings of Bloom and Woodhull-McNeal (1987), a lower backpack position

resulted in the least change in posture from an unloaded position. Although the effects of loose and tight shoulder straps were alluded to by Malhotra and Sen Gupta (1968), Grimmer et al. were the first to systematically study the effects of schoolbag adjustment on the physical demands placed on students. As a result of the conflicting evidence regarding backpack placement, further study is required so that backpack adjustment advice for school students may be more confidently prescribed.

In summary, although a number of studies have examined school students' responses to schoolbag carriage, there is still no clear evidence for a recommended maximum schoolbag weight. In addition, most studies have focussed on schoolbag weight and have not considered other aspects of schoolbag carriage such as schoolbag design, adjustment or carriage duration. Many of the studies have been conducted using Chinese school students who are shorter and lighter than their Caucasoid counterparts and therefore may differ in their physical capability. Further study of Caucasoid student responses to a range of schoolbag designs, adjustments, carriage durations and weights is needed.

## **Conclusion**

Manual handling guidelines are generally not applicable to schoolbag carriage. Schoolbag carriage guidelines have been developed, although they are not comprehensive and are generally not based on quality assured findings. The adult load carriage literature suggests that a person's response to load carriage depends on backpack weight, distance carried, walking speed, backpack adjustment and backpack design. In addition, a load carriage limit of approximately one third BW has been suggested for average sized, healthy young males. However, there appears to be a difference in the physical capabilities of adults and adolescents that cannot simply be explained by body mass differences. Therefore, it is unlikely that the load carriage limits for adult males are applicable to children. Epidemiological studies suggest that the relationship between schoolbag carriage and reported MSD is unclear. However, almost all studies agree that either schoolbag weight or exposure to schoolbag carriage is a risk factor associated with reported MSD. Despite widespread recommendations of a schoolbag weight limit of 10% BW, there is no

objective evidence that this limit is appropriate. However, significant changes in physiological, biomechanical and postural measures have been reported for schoolbag weights of between 15-20% BW for mainly Chinese participants. There is limited evidence that schoolbag adjustment affects posture, but no studies have comprehensively investigated the effects of backpack design, adjustment, carriage duration and weight on students' responses to schoolbag carriage. This information would add considerably to the development of evidence-based guidelines for schoolbag carriage.

## **Thesis aim**

The aim of this thesis is to examine the effects of schoolbag design, adjustment, carriage duration and weight on students' responses to carrying schoolbags. A secondary aim is to obtain objective evidence to assist in determining an upper schoolbag weight limit.

## **Specific studies**

In order to achieve the thesis aim, five separate studies were conducted:

### **1. Schoolbag design**

The design of a schoolbag may have a role in determining comfort and possibly preventing MSD in students, although this has never been demonstrated. The aim of this study was to compare school students' perceptions of three different backpacks especially designed for school use, with a recreational backpack chosen for its suitability for school use by its manufacturer.

### **2. Schoolbag carriage adjustment**

It is widely accepted that in order to maximally benefit from a particular backpack design it needs to be correctly adjusted. Despite this, no studies have systematically examined the effects of a variety of schoolbag adjustment configurations on the physical demands of schoolbag carriage. Therefore the aim of this study was to determine the effects of load weight, shoulder strap length, load distribution, gait

speed and the use of a hip-belt on shoulder strap tension forces and shoulder interface pressure during simulated school students' load carriage.

### **3. The temporal patterns of schoolbag carriage**

No studies have determined the temporal patterns of schoolbag carriage over a school day, despite indications that schoolbag carriage duration may be linked to MSD. The primary objective of this study was to quantify the temporal patterns of schoolbag carriage for an actual school day using activity monitoring and structured interviews. The secondary objective was to compare activity monitoring and structured interview methods for quantifying daily schoolbag carriage.

### **4. Schoolbag weight, shoulder strap adjustment and carriage duration**

Although postural and self-reported measures have been successfully used to compare schoolbag weights and designs, no studies have exposed students to realistic schoolbag carriage patterns before estimating an upper schoolbag weight. The objective of this study was to determine school students' postural and self-reported responses to five schoolbag weights and two shoulder strap adjustment conditions before, during and after a simulated school day. A second objective was to obtain objective evidence to assist in determining an upper weight limit for daily schoolbag carriage.

### **5. Schoolbag weight: A psychophysical approach**

A psychophysical approach has been successfully used in adult manual materials handling studies to identify maximal acceptable load weights. The advantage of the psychophysical approach is that an actual load weight chosen and considered by participants as 'acceptable' can be determined. The objective of this study was to determine a maximum acceptable schoolbag weight (MASW) using a psychophysical approach.

# Chapter 2

## *Schoolbag Design*

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### **Preface**

The design of a schoolbag may have a role in determining comfort and preventing MSD in students although this has never been demonstrated. Large differences in backpack design are associated with clear changes in biomechanical and physiological responses in adults. In contrast, subjective perceptual responses have proved to be a more effective method for comparing subtler differences in backpack designs.

Recently, schoolbags that incorporate ‘ergonomic’ features have become available in the marketplace. Although many of the manufacturers claim that the ‘ergonomic’ features of their schoolbags help to prevent MSD, there is no scientific evidence to support these claims. If ‘ergonomically designed’ schoolbags were to have a positive effect on the user, then correct backpack design should be included in future recommendations for schoolbag carriage along with other aspects of schoolbag carriage such as correct carrying technique and schoolbag weight.

Fashion is a complicating factor when considering good schoolbag design. An ‘ergonomically’ designed schoolbag will be ineffective if it is not purchased in the first instance, due to inferior school student appeal. The relationship between aesthetic and functional qualities and how they affect a person’s overall choice of backpack has never been reported.

The following study was carried out to explore the effects of schoolbag design on student’s subjective perceptual responses, based on both style and function. Four different backpacks that were intended for school use were compared. A paper describing this study was published in the journal *Applied Ergonomics*. It is reproduced verbatim as chapter 2 of this thesis.

## Comparison of four different backpacks intended for school use

Mackie, H. W., Legg, S. J., Beadle, J. and Hedderly, D. I. (2003). Comparison of four different backpacks intended for school use. *Applied Ergonomics*, 34, 257-264.

### Abstract

Four backpacks were evaluated for their desirability for use as school bags. Three of the four backpacks were specifically designed for school use based on previous research and ergonomic principles while the fourth (standard) backpack was chosen from two backpacks that their manufacturer considered to be the most likely to be used as a school bag. Twelve school students evaluated each of the backpacks firstly by examining them, again after donning them and again after walking with them on a treadmill by completing a questionnaire asking about the appearance, function and comfort of each backpack. On initial examination, the standard backpack was the most favoured but as functionality became increasingly important during the treadmill walk, the backpack which was designed specifically for school use and had two major compartments, substantial back padding and side compression straps became the most favoured. This particular design of backpack was reported as having the greatest practicality, being the least physically demanding and allowing the greatest balance and ease of walking. The results of this study suggest that school student's preference of backpack may change from when they first examine a prospective backpack to when they have used it. The study also shows that school students' preferred attributes in a backpack may shift over this time from 'style and image' to 'function and fit'.

Key words: backpack, school, design, ergonomics

## Introduction

Recent concern for the amount of weight that school students must carry to, from and around school (Negrini et al., 1999, NBPA, 1997) has prompted several studies of the demands of backpack use in school students (Cheung and Hong, 2001, Gill et al., 1999, Grimmer and Rubenstein, 1998, Grimmer et al., 1999, Hong et al., 2000, Sander, 1979, Pascoe et al., 1997, Voll and Kliment, 1977, Whitfield et al., 2001, Whittfield et al. 2002). However most studies have focussed on the weight carried as the main factor determining the demands of student's load carriage.

Total weight carried, duration and frequency of carriage and the manner in which the weight is carried all affect the demands on the musculoskeletal system and may affect the incidence of musculoskeletal pain or discomfort. In a study of 1269 high school students in Adelaide, Australia, Grimmer et al. (1999) found gender and age specific associations between recent low back pain, the amount of time spent sitting, the backpack load and the time spent carrying it. No other study has related the demands of carrying backpacks directly to reported musculoskeletal pain or discomfort.

As a result of the concern for the musculoskeletal health of school students, several backpack manufacturers have developed backpacks specifically designed for school use. Some of the features of the purpose designed backpacks include separate compartments so that load movement can be controlled, compression straps to hold the load closer to the centre of mass of the body, specially designed lumbar areas that are shaped so that some of the load is borne by the top of the buttocks and information tags to remind the user of correct load carrying habits.

Although purpose designed backpacks may help to alleviate the physical demands of school students, they will only serve their purpose if school students choose to use this type of backpack. Other factors such as style, cost and availability may also determine school student's decision to use a specifically designed backpack on a regular basis. Because of these other factors, other types of backpacks that seem more fashionable or desirable might prove to be the preferred choice of school

students despite the ergonomic benefits of school specific backpacks that have been specifically designed for use by school students.

Although many studies have compared different backpack designs and the effects that alternative designs have on the demands placed on the carrier (Bloom and Woodhull-McNeal, 1987, Bloswick et al. 1994, Bobet and Norman, 1984, Bygrave et al., 2002, Cruz and Legg, 2002, Frykman et al., 1994, Gerber et al., 1992, Legg et al., 1997, Legg et al. 2003, Legg et al. 2002, Lloyd and Cooke, 2000), none have compared backpacks that are specifically designed for school students.

The aim of this study was to compare school student's perceptions of three different backpacks especially designed for school use with a recreational backpack chosen for its suitability for school use by its manufacturer.

## Methods

Four backpacks, three designed for school use and one popular outdoor recreation design were evaluated. They included an Australian designed backpack (Backpack A), which included two main compartments, a comprehensive back padding system and compression straps, a British designed backpack (Backpack B) that included expandable side pockets and an internal waterproof bag for carrying wet swimming clothes or sports clothes and another Australian designed backpack (Backpack C), which featured a unique rigid design that encompassed a lumbar area that was designed to sit partially on the top of the buttocks. The fourth backpack was a New Zealand designed backpack (Backpack D) that was not manufactured specifically for school use but included a comprehensive harness system and waist strap.

Backpack D was selected by asking a sample of 28 people, each of approximately 13 years of age, on Auckland's main high street which one of two backpacks they would prefer to use as a school backpack. The two backpacks that were presented to this sample of people were the two backpacks that the backpack manufacturer decided were the most likely to be used as a school backpack. The most popular

backpack was then used in the main study along with the three purpose designed backpacks.

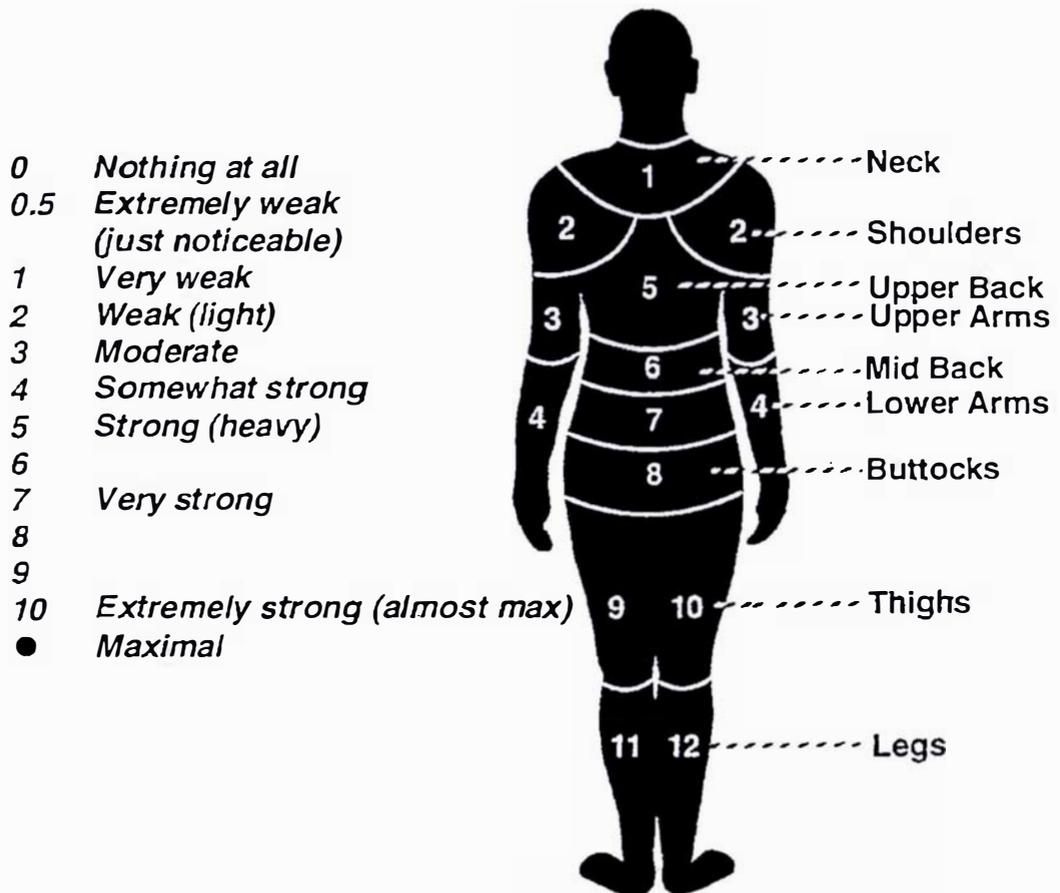
## Participants

Twelve school students (6 male, 6 female, mean (standard deviation) age, height and weight 12.6 (1.1) years, 1.61 (0.10) m and 52.5 (15.8) kg) volunteered for the study. Based on participants initial reactions to the backpacks, it was estimated that twelve participants would be sufficient to detect statistical differences in participants perceptions of the four backpacks.

## Questionnaire and data collection protocol

The evaluation of each of the backpacks involved the administration of a modified version of a questionnaire (Legg et al., 1997) to each student separately. Firstly, informed consent was obtained from each student and their age, weight and height was then measured and recorded. In the questionnaire, each student was then asked of any regional musculoskeletal discomfort that they were currently experiencing for each of 24 body regions (12 front and 12 back) using a regional body diagram (Corlett and Bishop, 1976) and a category ratio scale (CRS) rating method (Noble et al., 1983) (figure 1). They were also asked of the attributes they considered being important when choosing a backpack. At this stage the students had not seen any of the backpacks that were being evaluated. Each student was then presented with each backpack and was asked to choose a preferred backpack and provide reasons for their choice based on immediate impressions. Having chosen one of the backpacks they were then asked to spend two minutes wearing and examining the features of each backpack more closely. They were then asked again which backpack they preferred and why they preferred the backpack. This protocol was designed to replicate the conditions that might be experienced when evaluating backpacks in a retail outlet.

Each student was then asked to adjust each backpack to a weight they felt comfortable with (mean 3.7 Kg (Std dev 0.5)), don the backpack (after instruction

**Figure 1.** Category-ratio scale (CRS) ratings of perceived regional discomfort.

Source: Corlett and Bishop (1976) and Noble et al. (1983)

on how to correctly wear it) and then walk on a motor driven treadmill for 20 minutes while wearing the backpack at a speed with which they were comfortable (mean 2.9 km/hr (Std dev 0.2)). Each student had previously spent a small amount of time walking on the treadmill while adjusting the speed of the treadmill to his or her preferred speed. Self selected loads and treadmill speeds were selected so that the comfort of each participant was maximised, allowing them to focus on the backpack design, rather than the workload to which they were being subjected. The initially chosen backpack weight and treadmill speed was then maintained within each participant for the remainder of the study to ensure consistency across backpacks.

In the last five minutes of each student's 20-minute walk they were again asked to report any musculoskeletal discomfort they felt and were also asked to state their rating of perceived exertion (RPE). Immediately after the walk each student was asked about their perceived muscular strain in the shoulders, back, upper legs and lower legs, pressure on the shoulders and waist and ability to balance and walk while wearing the backpack. The process of walking for 20 minutes and the administration of the questions before and after the walk were repeated in a balanced design for each backpack. A 100 mm scale was used to score each question. Between evaluating backpacks, each participant rested completely for 15 minutes to minimise the effects of fatigue.

After each student had evaluated all four backpacks, they were again asked to identify their preferred backpack for school use and provide reasons for their decision.

Statistical comparisons between backpacks were calculated using an analysis of variance (ANOVA). ANOVA was performed using SAS Proc GLM, using participant as a blocking factor and backpack as the factor of interest. P-values were calculated for the results of all numerical answers on the questionnaire between all combinations of backpacks to indicate the level of significance of the difference between each pair of backpacks. The word "significant" was used to signify a P value that was less than 0.05 and the word "marginal" accompanied by the actual P value was used to signify a marginally statistically significant difference between backpacks.

## Results

For most of the questionnaire answers the range of scores given by different participants varied quite considerably. This may have indicated genuine differences between how different participants felt about each backpack, or it may reflect psychological characteristics of the participants, such as willingness to use the ends of the scales. Therefore, two separate analyses were carried out. One analysis based on the raw data, assumed that a participant who scored all the backpacks between,

for example, 30 and 40 genuinely thought the backpacks were more similar than a participant who scored the backpacks between 20 and 70. The other analysis was based on data standardised within participant; so each participant's scores were transformed so that they had a mean of 0 and a standard deviation of 1. This assumed that the perceived difference between the backpacks is the same size. Both analyses tended to give similar answers.

Comparisons between backpacks were categorised into questions as they appeared on the questionnaire.

## Initial assessment

### *Attributes reported as being important in a backpack*

A summary of student's most reported important attributes in a backpack included the need for comfort, quality, sufficient space and a fashionable style.

### *Initially chosen backpack*

At initial inspection of the backpacks, student's overall most favoured backpack was backpack D which was preferred by 7 out of 12 participants (figure 2) and was most often described as the most visually pleasing backpack.

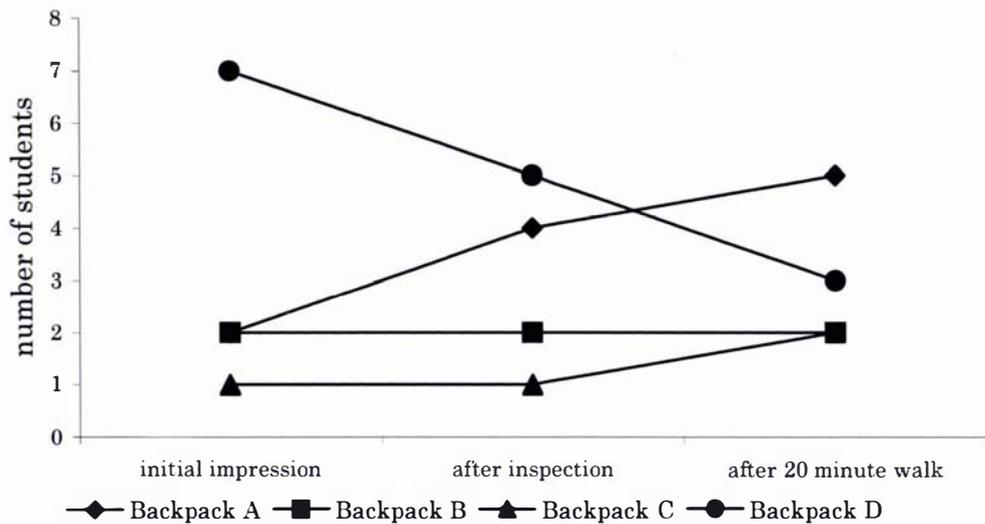
### *Positive attributes of initially chosen backpack*

The positive attributes of the backpack that students initially chose as their preferred backpack included general style and simple design for Backpack A, colours and side pockets for Backpack B, shape and colour for Backpack C and style and general appearance for Backpack D.

### *Chosen backpack after initial inspection*

After the two minute examination of each backpack, Backpack D was preferred by five participants, Backpack A was preferred by four participants, Backpack B was preferred by 2 participants and Backpack 1 was preferred by 1 participant (figure 2).

**Figure 2.** Preferred backpack after first impression, initial inspection and 20-minute walk.



*Positive attributes of favoured backpack after inspection of each backpack*

The positive attributes of the backpack that students chose as their preferred backpack after an inspection of each backpack included separate compartments, easy to open zips, firm back and overall comfort for Backpack A, wallet holder, side pockets and colour for Backpack B, less clutter and good access to the inside of the backpack for Backpack C and superior style and firm back for Backpack D.

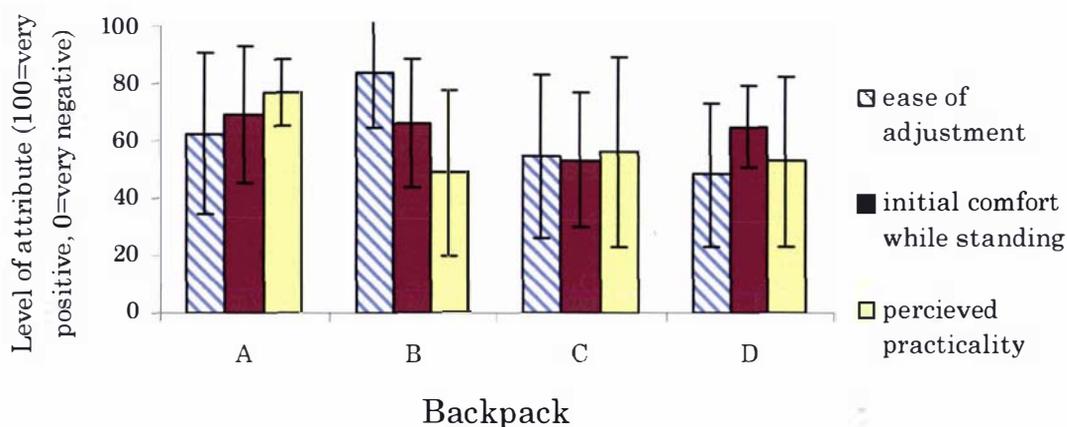
*Negative attributes of backpacks not favoured after inspection of each backpack*

Negative attributes of the backpacks that students did not choose as their preferred backpack after an inspection of each backpack included plain style for Backpack A, colour and perception that there is not sufficient space for Backpack B, too hard, square and not enough space for Backpack C and too many straps and difficult to open for Backpack D.

### Practicality

The raw data showed a marginal ( $p=0.075$ ) reported difference between backpacks (figure 3) while the standardised data showed a significant difference. With the raw data, Backpack A was reported as being significantly more practical than Backpacks B and D and marginally ( $p=0.065$ ) more practical than Backpack C. With the standardised data, Backpack A was reported as being significantly more practical than Backpacks B and D.

**Figure 3.** Mean (SD) reported practicality and ease of adjustment and initial comfort while standing of each backpack after initial inspection.



## Pre-walk

### *Ease of adjustment*

Both the raw and the standardised data showed a significant reported difference between backpacks (figure 3). With the raw data, Backpack B was significantly easier to adjust than the other backpacks. With the standardised data, Backpack B was significantly easier to adjust than Backpacks C or D and Backpack A was marginally ( $p=0.067$ ) easier to adjust than Backpack D.

### *Initial comfort while standing*

There were no significant differences in reported comfort for the backpacks (figure 3).

## Post Treadmill Assessment

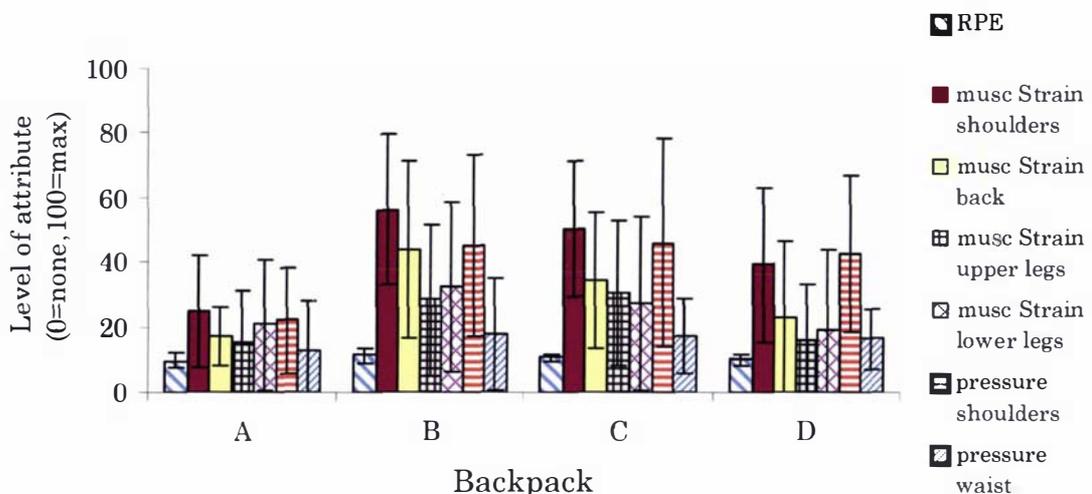
### *Rating of perceived exertion*

Both the raw and the standardised data showed a significant reported difference between backpacks (figure 4). With the raw data, Backpack B had a significantly higher mean RPE score than Backpacks A and D. With the standardised data, Backpack B had a significantly higher mean RPE score than Backpacks A and D and a marginally ( $p=0.082$ ) higher RPE score than Backpack C.

### *Strain on shoulders*

Both the raw and the standardised data showed a significant reported difference between backpacks (figure 4). With the raw data, significantly less strain on the shoulders was reported in Backpack A than Backpacks B and C, marginally ( $p=0.099$ ) less than Backpack D and marginally less strain on the shoulders was reported in Backpack D ( $p=0.094$ ) than Backpack B. With the standardised data, significantly less strain on the shoulders was reported in Backpack A than Backpacks B and C.

**Figure 4.** Mean (SD) reported physical demands following 20-minute treadmill walk.



### *Strain on the back*

Both the raw and the standardised data showed a significant reported difference between backpacks (figure 4). With the raw data, significantly higher strain on the back was reported in Backpack B than Backpacks A and D and significantly higher strain on the back was reported in Backpack C than Backpack A. With the standardised data, significantly higher strain on the back was reported in Backpack B than Backpacks A and D, while marginally higher strain on the back was reported in Backpack (p=0.079) than Backpack D.

### *Strain in upper legs*

Both the raw and the standardised data showed a significant reported difference between (figure 4). With both the raw and the standardised data, significantly less strain in the upper legs were reported in Backpacks A and D than Backpacks B and C.

### *Strain in lower legs*

The raw data showed no significant reported difference between backpacks (figure 4). The standardised data shows a marginal reported difference between Backpacks (p=0.060). With the standardised data, significantly more strain in the lower legs was reported in Backpack B than Backpacks A and D, while marginally more strain in the lower legs was reported in Backpack C (p=0.063) than Backpack D.

### *Pressure on shoulders*

Both the raw and the standardised data showed marginal reported differences between backpacks (p=0.095 for raw; p=0.110 for standardised, figure 4). With both the raw and the standardised data, significantly less pressure on the shoulders was reported in Backpack A than Backpacks B and C and marginally less pressure on the shoulders was reported in Backpack A (p=0.060 for raw; p=0.081 for standardised) than Backpack D.

### *Pressure on waist*

There was no difference in reported pressure on the waist between Backpacks. (figure 4).

### *Balance*

There was no difference in reported balance between Backpacks (figure 5).

### *Ease of walking*

Both the raw and the standardised data showed a significant reported difference between backpacks (figure 5). With the raw data, Backpack A was reported as allowing significantly greater ease of walking than Backpacks B and C and marginally ( $p=0.076$ ) greater ease of walking than Backpack D. Backpack B was reported as allowing significantly less ease of walking than Backpack D and marginally ( $p=0.064$ ) less ease of walking than Backpack C. With the standardised data Backpack A was reported as allowing significantly greater ease of walking than Backpacks B and C and marginally ( $p=0.052$ ) greater ease of walking than Backpack D. In addition Backpack D was reported as having significantly greater ease of walking than Backpack B.

### *Reported musculoskeletal discomfort*

The only significant difference between backpacks before the 20 minute walk was that Backpack C tended to cause more discomfort in the backs of the lower legs (tables 1 & 2). After the 20-minute walk, Backpack A was significantly less likely to produce pain in the back of the neck than the other backpacks. There were no significant differences between before and after the 20-minute walk.

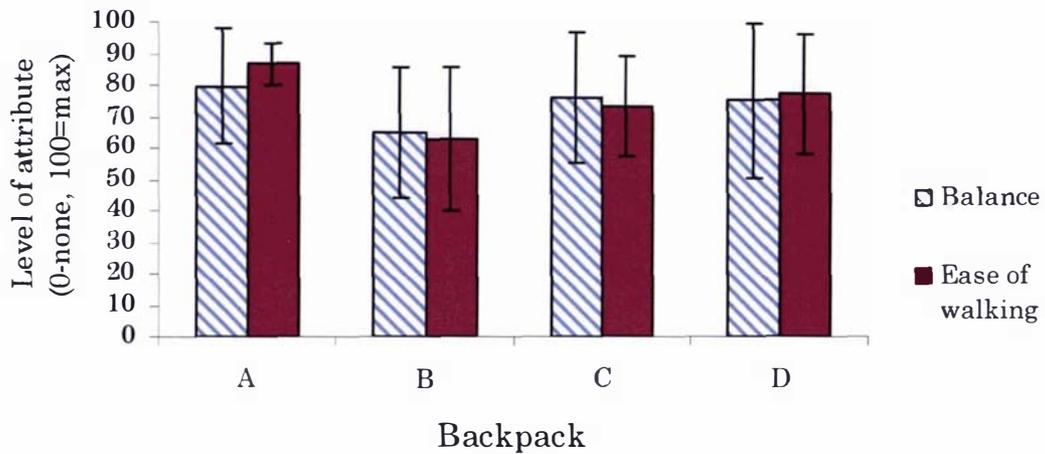
### *Overall most preferred backpack*

After each backpack had been fully assessed the most preferred backpack was backpack A (5 students) followed by backpack D (3 students) and then backpacks B and C (2 students each) (figure 2).

### *Positive attributes of each backpack after 20 minute walk*

Positive attributes of each backpack after the 20 minute walk included; general comfort, solid back, separate compartments and compression straps for Backpack A, side pockets, general comfort and favourable colours for backpack B, padding in the back for Backpack C and well designed shoulder straps, padding on the back and general style for Backpack D.

**Figure 5.** Mean (SD) reported balance and ease of walking following 20-minute walk.



#### *Negative attributes of each backpack after 20 minute walk*

Negative attributes of each backpack after the 20 minute walk included; itchy material, especially on the straps for Backpack A, overall poor design of straps for Backpack B, overall poor design of straps for Backpack C and uncomfortable straps and general discomfort for Backpack D.

#### *Reasons for choosing overall preferred backpack*

Reasons for choosing each backpack as the most preferred backpack included overall comfort, sufficient size, comfortable back padding and overall style for backpack A, stylish colours, lightweight feel of backpack and useful side pockets for Backpack B, overall comfort and ease of use for Backpack C and stylish design and general comfort for Backpack D.

**Table 1.** Reported musculoskeletal discomfort in the posterior and anterior side of the body, prior to 20 minute walk.

<b>Posterior side of body</b>						
Location	Number of reports from				p-values for differences between	
Backpack	A	B	C	D	Participants	Backpacks
Neck (1)	1	2	2	2	0.0351	0.8075
Shoulders (2)	1	1	1	1	0.0699	1.000
Upper Legs (9 & 10)	0	0	1	0	0.9199	0.2124
Lower Legs (11 & 12)	0	0	2	0	0.7460	0.0293
<b>Anterior side of body</b>						
Location	Number of reports from				p-values for differences between	
Backpack	A	B	C	D	Participants	Backpacks
Neck (1)	1	1	1	1	0.0699	1.000
Shoulders (2)	1	1	1	1	0.0699	1.000

**Table 2.** Reported musculoskeletal discomfort in the posterior and anterior side of the body, after 20-minute walk.

<b>Posterior side of body</b>							
Location	Number of reports from				p-values for differences between		
Backpack	A	B	C	D	Participants	Discomfort Before	Backpacks
Neck (1)	2	5	4	5	0.0028	0.1209	0.0275
Shoulders (2)	2	2	3	4	0.0761	0.2437	0.5140
Upper Back (5)	0	2	1	1	0.3054	--	0.2507
Mid Back (6)	0	1	0	1	0.7534	--	0.3270
Lower Back (7)	0	0	0	1	0.9221	--	0.2124
Upper Legs (9 & 10)	0	1	0	0	0.9221	1.000	0.2124
Lower Legs (11 & 12)	3	0	2	1	0.0690	0.4097	0.0112
<b>Anterior side of body</b>							
Location	Number of reports from				p-values for differences between		
Backpack	A	B	C	D	Participants	Discomfort Before	Backpacks
Neck (1)	1	2	2	0	0.0786	0.2437	0.0861
Shoulders (2)	1	2	2	0	0.0786	0.2437	0.0861
Upper Back (5)	1	0	0	0	0.9244	--	0.2124
Upper Legs (9 & 10)	1	0	0	0	0.9244	--	0.2124

## **Discussion**

The New Zealand designed backpack (Backpack D) that was not manufactured specifically for school use but included a comprehensive harness system and waist strap was clearly the initial backpack of choice by the students after the initial examination and this was reflected in their comments that it was the most stylish of the Backpacks. Conversely, after the 20-minute walk, the Australian designed backpack (Backpack A), which included two main compartments, a comprehensive back padding system and compression straps was the preferred backpack by the students and this was reflected by student's positive answers to the questions relating to practicality, pressure on the shoulders, strain on the shoulders and ease of walking.

Student's preferred choice of Backpack over time, suggests that initially the style of the backpack was the most influential attribute, but as students became more familiar with the backpack, function became more important. This finding also reflected student's reported musculoskeletal pain or discomfort after the 20-minute walk, with less reports of musculoskeletal pain or discomfort from backpack A than the other backpacks. This trend is perhaps not surprising as it would seem logical that most products require an initial attraction and then over time must perform functionally to maintain the user's positive image of that product. However, it is encouraging to confirm that school students also behave in this manner, when often during adolescence the style or image that a product portrays becomes more important than its function.

Although no studies of children's perceptions of different backpacks exist with which to compare these findings, Legg et al., 1997, Legg et al. 2003, Legg et al. 2002 all used perceptual methods to compare backpack designs. Unlike Legg et al., 1997, who found no differences in RPE between two backpack designs, in the present study the two overall most favoured backpacks also scored lower in RPE results for identical tasks. However, in agreement with Legg et al., 1997, scores for specific questions relating to muscular strain and pressure at different parts of the

body, particularly muscular strain in the shoulders and back and pressure on the shoulders, were reflected in participant's overall preference of backpack.

The results of the present study also agree with Legg et al. (2003) in that the overall preferred backpack also scored more positively in terms of muscular strain in the back and pressure in the shoulders.

Nevertheless, it must be noted that even at the end of the evaluation, style, colours and the overall 'look' of the backpack was still important and should not be overlooked when designing an ergonomically sound backpack. An important part of backpack ergonomics must be to attract school students to it so they will use it in the first instance. If the student chooses not to use an ergonomically designed backpack because another backpack initially looks more stylish, then all of the ergonomic principles that have been installed in the design of the backpack will have been lost. No studies exist that examine the aesthetic aspects of backpack design.

Although all students were instructed on the correct use of each backpack, when they actually walked on the treadmill they were free to adjust the backpack as they pleased. In many cases the waist belt was not used as these students preferred not to use it. This would have almost certainly affected the performance of the backpacks, especially Backpack D where the waist belt is an integral part of the design. However, if students refuse to use waist belts then the design should allow for this when backpacks are designed specifically for school use. Alternatively, sufficient education might be employed to encourage the use of waist belts.

Some features of Backpacks B and C were favoured by the students even though they were the overall least favoured of the backpacks. The presence of separate compartments and pockets seemed to be a favourable attribute and the extendable side pockets of Backpack B were also seen as positive.

In conclusion, the results of this study suggest that school student's preference of backpack may change from when they first examine a prospective backpack to when they have used it. The study also shows that school students' preferred attributes in a

backpack may shift over this time from ‘style and image’ to ‘function and fit’. This may mean that backpack manufacturers might spend more time on research and development and backpack ergonomics to ensure long-term customer loyalty.

## **Acknowledgement**

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## Post-script

The following post-script provides details of the published study that require expanding for the doctoral thesis requirements, or explanations of techniques used in response to examiners comments.

### Methods

A comparison of ergonomically designed schoolbags with a standard backpack was the basis for choosing the four backpacks that were used in this study. Pictures of the four backpacks would have made it easier for the reader to appreciate the design differences between them. The decision to omit pictures of the backpacks was partly influenced by the requirements of the journal in which the study was published. The journal editor maintained that the backpack's manufacturers should not be identifiable, which lead to labelling of the backpacks Backpack A, B, C and D. Omitting the pictures of the backpacks was a further measure in order to prevent the manufacturers of the backpacks from being identified. Within the study, the labels on the backpacks were covered with tape to prevent, as much as practically possible, participants identifying the backpack manufacturers. The backpacks were presented to participants in a balanced order to prevent any order effects.

The rationale for determining the sample size that was used, was based partly on practicality (this project was externally funded – which was limited, and therefore prevented a larger sample being used) and the success of a previous study using a similar methodology with similar sample numbers (Legg et al. 1997). Also, preliminary investigative work, prior to main data collection, demonstrated that twelve participants would be sufficient to determine statistically significant findings for our expected results. Finally, for a study design where participants are exposed to one or more treatments, the sample size required is unlikely to be much greater than 12 when reasonable precision is expected from the data. A power calculation would be of much greater importance when dealing with a purely cross-sectional study, where cause and effect are sought.

The questionnaire that was used in the study differed from Legg et al. 1997 in that it was reduced in length. It was considered that the participants (13-14 years) would not be able to match the sustained attention of the adult participants used in the Legg et al's study.

Additional information is required in order to sufficiently explain the statistical methods that were used. The discomfort ratings were skewed, with a high proportion of zeroes, which meant that the assumptions involved in ANOVA (additive effects, homogeneous normally distributed errors) were not reasonable. The data were reduced into binary responses (pain reported, yes or no). The probability of a positive report was then modelled using logistic regression. This allowed a comparison of differences in the rates of reporting between the backpacks (as well as a comparison between Pre Walk and After Walk discomfort) whilst allowing for differences between individuals. The results for this are correctly summarised in tables 1 and 2 of chapter 2.

## **Results**

Statistical findings that resulted in p-values that were slightly greater than 0.05, and in some instances approaching 0.1, have been referred to as marginally significant (with the associated p-value included). Although positive conclusions cannot be drawn from these results, they serve to suggest that there may be a trend, and that further study might reveal more positive findings. There has been no intention to draw positive findings from non-statistically significant findings.

The use of the CRS scale was not validated for school students prior to use, and therefore the results drawn from its use must be treated cautiously. However, the CRS results did reflect the questionnaire results in reporting neck and shoulder discomfort differences between backpacks, which provides overall support for the findings.

## **Discussion**

It is acknowledged that the questionnaire that was used was not formally validated, nor the reliability determined prior to its use. This means that the results from the

study must be interpreted cautiously. However, a slightly different longer version of the questionnaire was used successfully by Legg et al 1997, and the results of the present study were very clear in identifying Backpack A as the superior performing backpack. However, the performance of each backpack is measured in a number of ways, and all the measures used clearly indicated that Backpack A was superior to the others in terms of function. This would indicate that the questionnaire has been effective in determining what was intended of it.

The discomfort that was reported is most likely to have been due to the backpacks as the questionnaire was administered prior to the 20-minute walk and again afterwards. There were no comfort differences reported prior to the walk, whereas after the walk there were differences between the backpacks. The study could have been strengthened by the inclusion of a control condition in which no backpack was carried.

# Chapter 3

## *Schoolbag carriage adjustment*

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### **Preface**

In the previous chapter it was demonstrated that backpack design can affect school student's reported musculoskeletal discomfort and overall choice of schoolbag. However, it is widely accepted that in order to maximally benefit from a particular backpack design, it needs to be correctly adjusted. Most adult recreational backpack manufacturers include some form of instruction on how to correctly adjust a backpack prior to use.

Although a few studies have demonstrated that different backpack positions on the back result in postural changes in both adults and children, no studies have systematically examined the effects of a variety of backpack\* configurations on shoulder forces and pressure. The shoulder area, which bears most of a schoolbag load is subject to pressure from the backpack shoulder straps and is therefore the area of the body that is most directly affected by backpack carriage.

In the following study, the effects of different combinations of shoulder strap length, load placement, hip-belt use, backpack weight and gait speed on shoulder strap tension and interface pressure were examined using a mechanical load carriage simulator. A paper describing this study has been published in the journal *Applied Ergonomics*. It is reproduced verbatim as chapter 3 of this thesis.

\* In the following study the term 'backpack' rather than 'schoolbag' is used as backpacks have been identified as the most commonly used type of schoolbag (see chapter 1 – Review of literature)

## The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure

Mackie, H. W., Stevenson, J. M., Reid, S. A. and Legg, S. J. (2004). The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. *Applied Ergonomics*, 36, 199-206.

### Abstract

Recently, several studies have addressed the physical demands of school student's load carriage, in particular the load weight carried, using physical demands indicators such as oxygen consumption, gait and posture. The objective of this study was to determine the effects of different load carriage configurations on shoulder strap tension forces and shoulder interface pressure during simulated school student's load carriage. A load carriage simulator was used to compare shoulder strap forces and shoulder pressure for 32 combinations of gait speed, backpack weight, load distribution, shoulder strap length and use of a hip-belt. The results showed that the manipulation of backpack weight, hip-belt use and shoulder strap length had a strong effect on shoulder strap tension and shoulder pressure. Backpack weight had the greatest influence on shoulder strap tension and shoulder pressure, whereas hip-belt use and then shoulder strap adjustment had the next greatest effects, respectively. While it is clear that researchers and practitioners are justified in focusing on load magnitude in backpack studies as it has the greatest effect on shoulder forces, hip-belt use and shoulder strap adjustment should also be examined further as they too may have significant effects on the demands placed on backpack users. Based on the present findings, school students should wear their backpacks with the least weight possible, use the hip-belt if present, allow a reasonable amount of looseness in the shoulder straps and should position the heaviest items closest to their back. However, more detailed work using human participants needs to be undertaken before these recommendations can be confirmed.

**Keywords:** Strap tension, pressure, schoolbag, simulator

## Introduction

Growing suspicion that the loads school students carry to, around and from school are frequently too high has prompted research into the physical demands of school student's load carriage (Chansirinukor et al., 2001; Cheung & Hong, 2000; Grimmer et al., 2002; Grimmer & Williams, 2000; Hong et al., 2000; Mackie et al., 2003, Malhotra & Sen Gupta, 1965; Pascoe et al., 1997; Sander, 1979; Voll & Klimt, 1977; Whitfield et al., 2001). However, it is difficult to demonstrate that loads carried by school students are directly associated with reported musculoskeletal pain or discomfort as there are many other factors such as physical capability, other physical activities, poor seating, growing pains or psychosocial factors that may contribute to reported pain or discomfort (Troussier et al., 1994; Watson et al., 2002).

Researchers have therefore tended to study the effects of load carrying on physiological and biomechanical measures in children and adolescents such as oxygen consumption (Hong et al., 2000; Malhotra & Sen Gupta, 1965), gait (Cheung & Hong, 2000; Pascoe et al., 1997; Wang et al. 2001) and posture (Chansirinukor et al., 2001; Grimmer et al., 2002; Grimmer & Williams, 2000; Malhotra & Sen Gupta, 1965; Pascoe et al., 1997; Wang et al., 2001). Wang et al. (2001) also studied ground reaction forces in order to determine the effects of carrying school-related loads.

Physiological and biomechanical measures such as oxygen consumption and gait are undoubtedly altered as a result of load carriage (Goldman & Iampietro, 1962; Kinoshita, 1985; Knapik, 1996; Legg et al., 1985; Legg et al., 1986) but whether these changes are indicative of eventual injury is unknown. Increases in oxygen consumption or increases in support phase time during gait may be the body's natural way of safely accommodating the extra load placed on it.

A more direct method of determining the physical demands of load carriage in school students would be to measure the external forces that directly relate to carrying a backpack, such as the pressure on the shoulders that occur as a result of

the tension in the shoulder straps of a backpack. Bryant et al. (1996) described a biomechanical model for the forces that act within the person/backpack system when load carrying. In this model the weight force of the backpack is resisted mostly by the resistive forces of the shoulders, hips and lower back via the shoulder straps and hip-belt. Given that using the hip-belt to increase the load on the hips is seen as positive during load carriage, measuring the forces at the shoulder during load carriage would provide a relevant indicator of the demands placed on the backpack user.

The magnitude of the loads that school students carry has also been the focus of school load carriage researchers (Cheung & Hong, 2000; Hong et al., 2000; Maholtra & Sen Gupta, 1965; Pascoe et al., 1997; Voll & Klimt, 1977; Whitfield et al., 2001) and 10% of body weight (BW) is generally accepted as a recommended maximum load for school students (Sander, 1979; Voll & Klimt, 1977). Recently studies have shown that no significant changes in oxygen consumption or gait occur until school students are carrying 15%-20% of body weight (Cheung & Hong, 2000; Hong et al., 2000; Pascoe et al., 1997), which may support a school load carriage limit of 10% BW. What seems more certain is that 20% BW as a load for school students is excessive (Cheung & Hong, 2000; Hong et al., 2000).

The variations reported in school student's responses to carrying loads may be because a person's carrying capacity is affected not only by the magnitude of the load they carry but also by the way the load is carried, the duration of carriage, the frequency of carriage and the physical capabilities of the person. These other factors must also be considered when attempting to determine the overall physical demands placed on the user.

Bygrave et al. (2000) appear to be the only authors to have studied the adjustment of a single backpack in adults. They found that the tightness of fit of a backpack (adjustment in the shoulder straps, chest strap and hip-belt of 3 cm) had an effect on lung function in 12 healthy males wearing a 15 kg backpack. Using different backpack designs Lloyd and Cooke (2000) and Kinoshita (1985) both found that distributing the weight of the backpack between the front and the back of the body

lead to improvements in gait measures. In children, Grimmer et al. (2002) found that more loose shoulder straps allowed a more upright, natural posture than tighter shoulder straps where the backpack is carried higher on the back.

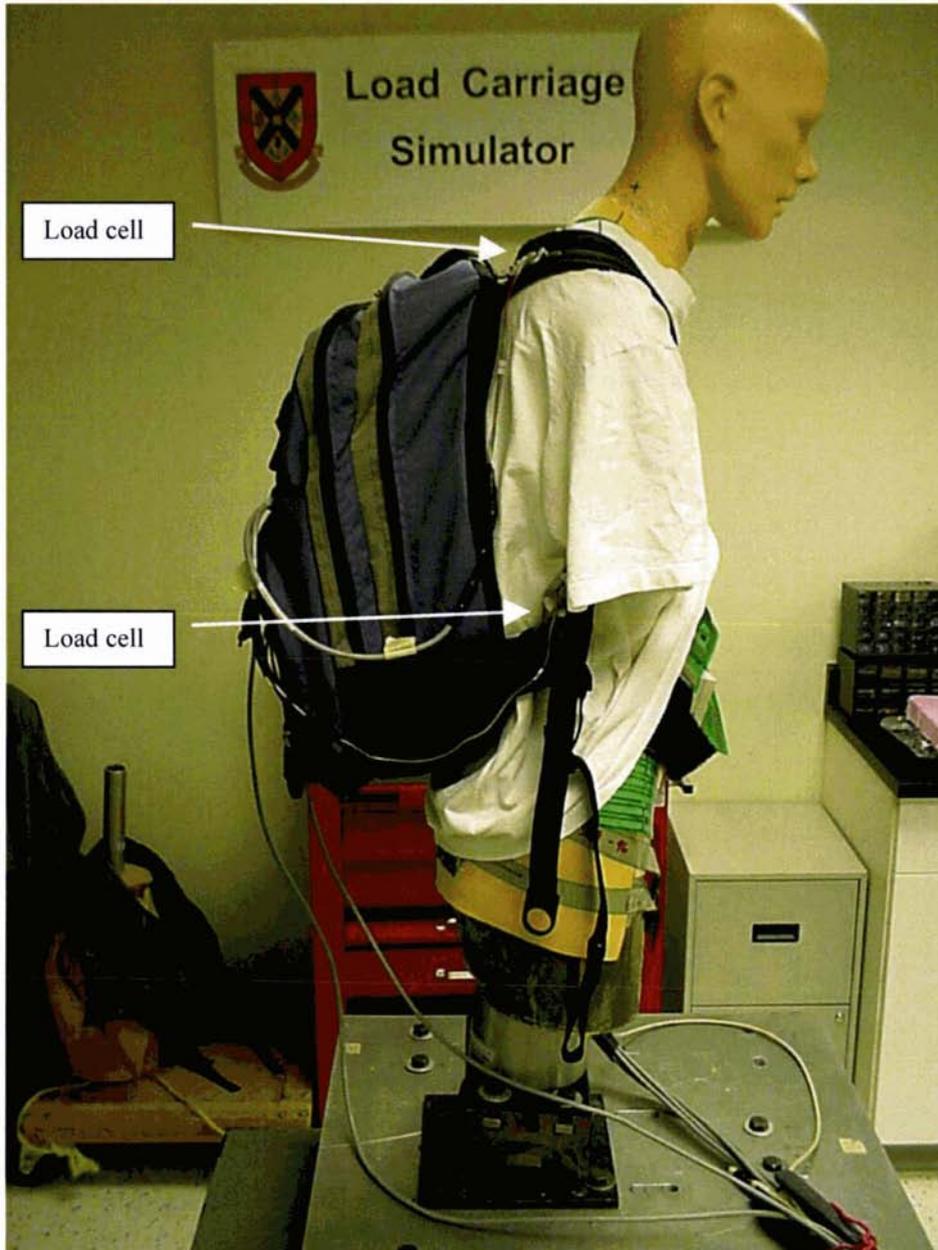
Although these studies have addressed backpack configuration, no studies to date have attempted to study the effects of many different backpack adjustments on the backpack forces that directly affect school students. However, in order to carry out such a study, a large number of trials would need to be performed in order to test different combinations of backpack adjustments for each individual from a sample group large enough to account for the variation of results expected from human participants.

Bryant et al. (2001) recommend that a load carriage simulator is useful in screening a large number of backpack designs or configurations prior to more detailed analyses using human participants. A load carriage simulator might, therefore, be an efficient way of evaluating a large number of school load carriage configurations, prior to a more detailed evaluation of potentially beneficial configurations using school students in the future. The objective of this study, therefore, was to determine the effects of load weight, shoulder strap length, load distribution, gait speed and the use of a hip-belt on shoulder strap tension forces and shoulder interface pressure during simulated school student's load carriage.

## **Methods**

All trials were conducted on a load carriage simulator that was designed and built by the Ergonomics Research Group at Queens University, Ontario, Canada and is the property of Defence Research and Development Canada (Stevenson et al., 2004). The load carriage simulator (figure 1) consists of a programmable three degree of freedom pneumatically driven platform, which supports interchangeable rigid mannequins.

**Figure 1.** Load carriage simulator used for data collection (tight shoulder straps configuration shown).



Vertical displacement, rotation about the anterior/posterior axis (side lean) and rotation about the medial/lateral axis (forward lean) are user programmable from a menu. A skin analogue (Bocklite®) covers the surface of the mannequin.

Anterior/posterior lean of the mannequin is typically set by balancing the anterior-posterior moment due to backpack loads. In previous studies (Cheung & Hong, 2000; Maholtra & Sen Gupta, 1965; Pascoe et al., 1997) the change in anterior lean of the trunk in school children when carrying different loads has been shown to be very small or negligible until a load change of 17-20% BW was administered. Therefore, in this study, the mannequin was fixed to the motor of the simulator with an anterior tilt of five degrees (balanced in the anteroposterior plane) to maintain consistency between trials.

A mannequin representing a 5<sup>th</sup> percentile Canadian armed forces female (weight 52.8 kg and height 1.55 m) was used (figure 1) as it most closely resembled the anthropometric characteristics of 13 year old school students, which have been reported as carrying the greatest loads across all school students (Grimmer & Williams, 2000, Pascoe et al., 1997, Whittfield et al., 2001) and therefore may be at the greatest risk of injury. A commercially available school backpack (figure 1), with no internal or external frame, but with adjustable shoulder straps and waist belt was used for the study. The backpack was modified to accommodate custom built load cells at the top and at the bottom of the shoulder straps so that tension could be measured at these points, giving an indication of the shoulder reaction force. The linearity of the load cells' response to loading was tested up to 50 N. Correlation coefficients of  $r = 0.999$  and  $r = 0.998$  were determined for the bottom and top shoulder strap load cells, respectively. Forces were measured on the right side of the backpack while dummy load cells of identical dimensions were used on the left side to ensure the symmetry of the school backpack. The load cells were hardwired to an amplifier and a personal computer and force data was collected at 20 Hz, which was the limit of the capability of the system.

Shoulder pressure during load carriage has previously been measured using Tekscan pressure sensors (Martin & Hooper 2000). A pressure sensor (Fscan 9811, Tekscan) was placed over the most superior aspect of the right shoulder of the mannequin so that changes in pressure due to forces from the shoulder straps could be measured. Gathering absolute quantitative data using this sensor when placed on a curved surface proved ineffective as the bending of the sensor created an offset, so only

changes in raw pressure (the sum of the pressures measured in each of 96 pressure sensitive cells) was used. Raw pressure measurements were collected at 50 Hz using the same data acquisition software as the load cells. Extra precautions were taken by collecting unloaded baseline data from the Tekscan system before and after each trial, to account for any drift in the signal from the sensor.

Both the load cells and the pressure sensors proved to be highly reliable. Correlation coefficients for test/re-test mean and peak forces were  $r = 0.986$  and  $r = 0.979$ , respectively. Correlation coefficients for test/re-test mean and peak pressures were  $r = 0.945$  and  $r = 0.956$ , respectively.

The validity of the load carriage simulator's ability to predict musculoskeletal discomfort in soldiers has been established by Bryant et al. (2001). Significant positive correlations were shown between shoulder pressure and forces on the simulator and soldier's reported musculoskeletal discomfort. In the present study, statistically significant ( $P < 0.01$ ) correlation coefficients of  $r = 0.556$  and  $r = 0.635$  for mean and peak load cell / pressure sensor comparisons, respectively, demonstrated the validity of the overall measurement system. There appear to be no studies that demonstrate the validity of the simulator's ability to reproduce human movement.

Before each trial the backpack was placed on the mannequin in a standardised manner. Measurements between markers on the side and back of the neck of the mannequin and the shoulder strap and the top of the backpack were used to ensure consistent backpack placement.

Five load carriage adjustment parameters were determined based on the variations of load carriage that school students were considered to most commonly experience. Gait speed ('Walking' and 'running'), backpack weight, load distribution, shoulder strap length and use of a hip-belt were manipulated so that 32 possible combinations of load carriage configuration were evaluated.

Simulator walking and running step rates (1.3 and 1.5 steps per second, respectively) and center of mass vertical displacements (4.5 and 6.0 cm, respectively) were used based on gait kinematics information from Unnithan & Eston (1990) and Rose & Gamble (1994). Step rate and center of mass vertical displacement were the only programmable components of the simulator's gait speed. It is acknowledged that only manipulating these two variables is not sufficient to realistically differentiate between real walking and running. However, they are likely to have the greatest effect on the forces that effect the shoulder during load carriage.

Backpack weights used were 10% (5.3 kg) and 15% (7.9 kg) of the representative BW of the mannequin. These weights were chosen as they represented the current recommended load carriage limit for school students (10% BW) and 5% greater than the recommended limit, so that the effects of heavier, yet realistic loads could be examined. Load distribution was termed as 'close' and 'distant'. Five text books were used to pack the school backpack with the heaviest books closest to the back of the mannequin for the 'close' load distribution condition (centre of mass 5.5 cm from inner backpack wall) and the heaviest books farthestmost from the back of the mannequin for the 'distant' load distribution condition (centre of mass 11 cm from inner backpack wall). The shoulder straps were adjusted and checked using a tape measure before each trial, with the 'tight' straps condition defined as a distance of 7 cm from the tip of the shoulder strap adjustment buckle to the lower connection of the shoulder strap to the backpack. This adjustment represented the backpack fitting close to the upper back (figure 1). The 'loose' straps condition, representing the backpack sitting lower on the back of the mannequin, was defined as a distance of 24 cm from the tip of the shoulder strap adjustment buckle to the lower connection of the shoulder strap to the backpack. The hip-belt was either used or not used. When it was used the hip-belt tension was standardized to 13.6 kg using a Shimpo tensiometer before each trial.

For each trial, the simulator was allowed to run for 10 gait cycles, prior to data collection. Two ten second trials were collected for each backpack configuration so that the reliability of the system could be evaluated. Between each trial, the backpack position on the mannequin was checked and adjusted if necessary.

Pressure and force data were analysed using SPSS statistical analysis software. Data from the two trials for each load carriage configuration were combined and means and standard deviations were calculated both for the overall data and for the peaks in each cycle for each trial. Separate, single factor, within groups, analyses of variance (ANOVA) with an alpha level of 0.05 were used to compare the data between each variation of walking/running, backpack weight, load distribution, strap length and use of a hip-belt. Between groups ANOVA were used to test for interactions between backpack configurations.

## **Results**

Tables 1 and 2 show the mean and standard deviation (SD) overall and peak shoulder strap forces and shoulder pressures for each variation of backpack weight, use of hip-belt, strap length, load distribution and walking/running. The percentage difference between the means of each variation of overall and peak force and pressure is also shown along with the p-value, demonstrating the level of statistical significance of the differences between the means of each variation.

Load weight had the greatest influence on shoulder strap forces with a load of 15% BW producing 50% greater overall force ( $p<0.001$ ) and 36% greater peak force ( $p<0.001$ ) than a load of 10% BW. This was followed by hip-belt use where the non-use of the hip-belt produced 40% greater overall forces ( $p<0.001$ ) and 41% greater peak forces ( $p<0.001$ ) than when a hip-belt was used and shoulder strap length where tight straps produced 37% greater overall forces ( $p<0.001$ ) but only 10% greater peak forces ( $p=0.151$ ) than loose shoulder straps.

Variations in load placement and walking / running had much less effect on shoulder strap forces than load weight, hip-belt use and shoulder strap adjustment. For load placement, having the weight distributed farthestmost away from the back only increased overall shoulder strap forces by 6% ( $p=0.494$ ) and peak shoulder strap forces by 10% ( $p=0.143$ ). For walking and running, running only increased overall shoulder strap forces by 1% ( $p=0.914$ ) and peak shoulder strap forces by 8% ( $p=0.286$ ).

**Table 1.** Mean and Standard deviation (SD) overall and peak shoulder strap forces (Newtons) for different load carriage configurations.\* = difference statistically significant ( $p < 0.05$ ), \*\* = difference statistically significant ( $p < 0.01$ ), \*\*\* = difference statistically significant ( $p < 0.001$ ).

Load carriage variable	Adjustment 1		Adjustment 2		% diff Overall	% diff Peak
<b>Load weight</b>	<b>10% of body weight</b>		<b>15% of body weight</b>		50***	36***
	Overall	Peak	Overall	Peak		
	22.5 (7.0)	38.0 (10.1)	33.8 (8.4)	51.7 (9.6)		
<b>Hip belt</b>	<b>Used</b>		<b>not used</b>		40***	41***
	Overall	Peak	Overall	Peak		
	23.5 (10.1)	37.2 (10.6)	32.9 (6.2)	52.5 (7.7)		
<b>Straps</b>	<b>Loose</b>		<b>Tight</b>		37***	10
	Overall	Peak	Overall	Peak		
	23.8 (9.4)	42.7 (14.1)	32.5 (7.7)	47.0 (9.1)		
<b>Load placement</b>	<b>close to back</b>		<b>distant from back</b>		6	10
	Overall	Peak	Overall	Peak		
	27.4 (10.8)	42.7 (13.1)	29.0 (8.3)	47.1 (10.5)		
<b>Gait speed</b>	<b>walking</b>		<b>running</b>		1	8
	Overall	Peak	Overall	Peak		
	28.1 (9.8)	43.2 (11.4)	28.3 (9.5)	46.5 (12.5)		

The pattern of results for shoulder pressure was similar to those shown for shoulder strap forces. Load weight had the greatest influence on shoulder pressure with a load of 15% BW producing 70% greater overall shoulder pressure ( $p < 0.001$ ) and 65% greater peak shoulder pressure ( $p < 0.001$ ) than 10% BW. This was followed by hip-belt use where the non-use of the hip-belt produced 44% greater overall shoulder pressure ( $p = 0.001$ ) and 47% greater peak shoulder pressure ( $p < 0.001$ ) than when the hip-belt was used. For strap length, tight straps produced 40% greater overall shoulder pressure ( $p < 0.001$ ) and 28% greater peak shoulder pressure ( $p = 0.020$ ) than loose straps.

**Table 2.** Mean and Standard deviation (SD) overall and peak shoulder pressure (raw pressure) for different load carriage configurations.\* = difference statistically significant ( $p < 0.05$ ), \*\* = difference statistically significant ( $p < 0.01$ ), \*\*\* = difference statistically significant ( $p < 0.001$ ).

Load carriage variable	Adjustment 1		Adjustment 2		% diff Overall	% diff Peak
	Overall	Peak	Overall	Peak		
<b>Load weight</b>	<b>10% of body weight</b>		<b>15% of body weight</b>		70***	65***
	Overall	Peak	Overall	Peak		
	222 (95)	271 (112)	378 (128)	446 (136)		
<b>Hip belt</b>	<b>Used</b>		<b>not used</b>		44**	47***
	Overall	Peak	Overall	Peak		
	246 (138)	290 (143)	355 (114)	427 (129)		
<b>Straps</b>	<b>Loose</b>		<b>Tight</b>		40***	28*
	Overall	Peak	Overall	Peak		
	250 (138)	315 (165)	350 (117)	402 (125)		
<b>Load placement</b>	<b>close to back</b>		<b>distant from back</b>		3	4
	Overall	Peak	Overall	Peak		
	295 (151)	352 (164)	305 (122)	365 (140)		
<b>Gait speed</b>	<b>walking</b>		<b>running</b>		-21*	-16
	Overall	Peak	Overall	Peak		
	336 (141)	390 (147)	264 (124)	326 (152)		

For shoulder pressure, variations in load distribution again had much less effect on shoulder pressure than load weight, hip-belt use and shoulder strap adjustment. Having the weight distributed farthestmost away from the back only increased overall shoulder pressure by 3% ( $p=0.772$ ) and peak shoulder pressure by 4% ( $p=0.720$ ). Walking and running had the opposite effect on shoulder pressure than it did on shoulder strap forces. Walking produced 21% more overall shoulder pressure ( $p=0.031$ ) and 16% more peak shoulder pressure ( $p=0.096$ ) than running.

One interaction between load carriage adjustments was statistically significant. The interaction between the shoulder strap adjustment hip-belt use was statistically

significant ( $p < 0.001$ ) for overall and peak shoulder strap forces and shoulder pressure. The interaction meant that the loose shoulder strap adjustment was more effective in reducing shoulder forces when the hip-belt was worn.

## Discussion

Load weight was clearly the most influential of the load carriage variables that were studied. This seems reasonable as the gravitational pull on the contents of the backpack due to the added load would have the greatest effect on the forces at the shoulder straps. More surprising was that the magnitude of the pressure on the shoulder increased disproportionately to the increase in load added to the backpack. The variation in backpack loads was 50% (10% BW – 15% BW), therefore forces and pressure at the shoulder would have been expected to increase by 50% in accordance with Newton's law of reaction forces. The differences in overall and peak shoulder strap force between 10% BW and 15% BW were 50% and 38% respectively, which seems approximately proportional to the load increase, whereas the differences in overall and peak shoulder pressure between 10% BW and 15% BW were 70% and 65% respectively suggesting that the load might be increasingly demanding disproportionately to the weight carried. This might be explained by the frictional forces at the shoulder and back that partially support the load of the backpack having less of an effect at higher loads. This phenomenon was reflected by Bryant et al. (1996) who found that the proportion of the load weight being supported by the shoulders compared with other contact points on the body increased as the load weight increased. However, it must be remembered that currently, the relationship between frictional and pressure forces on the simulator compared with school students is not known. This is further complicated by the fact that for much of the shoulder area, the shoulder straps were in direct contact with the clothing rather than the Bocklite® skin analogue, although Hooper & Jones (2002) suggested that clothing layers have no effect on the transmitted pressure to the skin.

Although load weight had the greatest effect on shoulder forces and pressure, the use of a hip-belt and looser shoulder straps also significantly reduced shoulder forces. The effect of the hip-belt is understandable as its use means that more of the weight

is borne by the hips, lower back and abdominal region, therefore reducing the demands on the shoulders.

The effect of looser shoulder straps is not as obvious. Perhaps the looser shoulder straps meant that there was more of each strap in contact with the body, which would lead to greater frictional forces and therefore less pressure on the shoulder. Alternatively, this phenomenon might be explained by the fact that in the loose position the straps are pulling more vertically, which is in the direction required to counter the effects of gravity on the backpack and would therefore require less overall force in the shoulder straps. A complication to this trend is that when the loose and tight shoulder straps data is further categorized by hip-belt use, the positive effects of looser shoulder straps is much greater when the hip belt is worn. Likewise, the use of the hip-belt appears to be more effective when loose shoulder straps are used. Simultaneous measurement of shoulder strap and hip-belt pressures in future research would more accurately describe how contact pressures are shared when the hip-belt is worn during schoolbag carriage. Although Jones & Hooper (2003) have measured pressure in shoulders and hips in response to military load carriage, this has never been carried out for school students.

Grimmer et al. (2002), found that looser straps allow school students to stand in a more upright posture. Based on the findings to date, there may be some benefit in school students adjusting shoulder straps to a more loose position, especially if the hip belt is used. Conversely, walking with a lower backpack center of mass has been shown to cause greater forward lean in adults (Bloom & Woodhull-McNeal, 1987) and therefore further clarification is required.

Load distribution had much less of an effect on the shoulder strap forces and pressure at the shoulder than load, hip-belt use and shoulder strap adjustment. The greater torque that is generated by distributing the heavy contents of the backpack further away from the back should increase shoulder strap forces due to the increased resistance torque that the wearer must exert. However, the difference in weight distribution in this study was clearly not enough to invoke significant differences in overall or peak shoulder strap forces and shoulder pressure. By more

greatly changing the weight distribution of a backpack via the use of balance pockets on the front of a backpack, both Kinoshita (1985) and Lloyd & Cooke (2000) found that positive differences in load carrying ability were obtained, which is more conclusive than the findings of the present study. The effects of increasing the distance of the center of mass position from the back of the mannequin might have been better detected by measuring the lumbar force applied by the backpack.

The effect of gait speed on shoulder strap forces and shoulder pressure was unexpected. It was expected that both shoulder strap forces and shoulder pressure would increase as gait speed increased in accordance with Newton's second law in which force is a function of mass and acceleration. The increased vertical acceleration from running should have produced greater shoulder forces. However, running produced significantly less overall pressure on the shoulders and there was no effect on peak shoulder strap forces and peak shoulder pressure. One possible explanation for this is that the different gait speeds produced different relative simulator and backpack movements due to different timing of the phases of the simulator and the backpack movement. If this is the case then the effects of phase differences in person-backpack movement on forces on the shoulder should be examined more thoroughly as it might justify the use of devices such as springy shoulder straps, which may promote such interactions.

Currently, there are no normative data with which the results of the present study can be compared, apart from the increasing evidence that a load of 17% of body weight may be excessive and a load of 20% of bodyweight almost definitely is excessive for school students (Cheung & Hong, 2000; Hong et al., 2000; Pascoe et al., 1997). If shoulder strap forces were found to increase by at least 50% when the load was increased from a currently 'acceptable' load of 10% BW to a 'possibly unacceptable' load of 15% BW in the present study, then the increases in shoulder forces and pressure of approximately 40% as a result of tight shoulder straps or not wearing a hip-belt, must also be significant enough to affect the wearer.

A statistically significant interaction was observed where the benefit of looser shoulder straps was greatly improved when the hip-belt was used. This phenomenon

may be explained by the hip-belt controlling the load and preventing relative movement between the backpack and the person. There may be other, more subtle interactions that also exist, which should be further studied in more detail, using human participants.

Limitations to the present study include measuring force at 20 Hz and the validity of using Tekscan pressure sensitive pads on a curved surface. However, the effects of these limitations on the findings have been minimized by reproducing identical trials, only using changes in shoulder pressure and measuring baseline values for shoulder pressure prior to data collection.

Another limitation of this study includes the unknown ability of the load carriage simulator to accurately reproduce human movement and posture and respond to contact pressures. However, the main purpose of the load carriage simulator is not to perfectly reproduce human movement, but to allow highly reproducible comparisons of load carriage systems. In addition, the ability of the simulator to predict soldier's musculoskeletal discomfort as demonstrated by Bryant et al. (2000) indicates a positive relationship between simulated and human backpacking. It is unknown whether this relationship is also true for school students.

A similar study to the present one, using human participants to examine these findings in a more realistic setting would be useful. However, the logistical implications of conducting such a study with remotely near the same reliability as the simulator used in the present study are enormous. A combination of the two methods, as suggested by Bryant et al. (2001), where the simulator is used to screen large numbers of different load carriage adjustments prior to more specific human based investigations might be appropriate.

## **Conclusion**

Load weight, hip-belt use and shoulder strap length had the greatest effects on shoulder strap tension forces and shoulder interface pressure. Load distribution had much less of an effect on shoulder forces, however, keeping the load close to the

back may still assist in reducing discomfort and perhaps injury. It is unclear what effect gait speed had on shoulder forces. Based on the demands placed on the shoulder as a result of simulated load carriage, school students should limit the amount of weight carried, use a hip-belt, adjust the shoulders straps to a fairly loose position and perhaps position the heaviest items closest to the back. However, more detailed work with human participants needs to be conducted before these recommendations can be confirmed.

## **Acknowledgement**

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## Post-script

The following post-script provides details of the published study that require expanding for the doctoral thesis requirements, or explanations of techniques used in response to examiners comments.

### Methods

The use of Tekscan pressure sensitive film proved to be ineffective when the film was placed over the curved surface of the mannequin's shoulder. It was discovered that the curved surface created an offset in the magnitude of pressure that was measured. As a result of concerns regarding the response characteristics of the pressure sensitive film, only raw data was collected (it was not converted into N/cm) and only changes in pressure were analysed statistically. The use of changes in pressure measured using this film is supported by the fact that whatever the response characteristics of the film, it was likely that this remained the same for all trials, as the film was not moved during the data collection period. However, the actual shape of the sensor was not measured during the trials. Furthermore, the similarity between the pressure data and the load cell data provides validity for the findings of the pressure data. The limitations of the pressure sensitive film were firmly acknowledged prior to data collection, which is why load cell forces were also measured.

The step frequency that was used on the simulator was 1.3 and 1.5 steps per second, respectively ('walking' and 'running'). Given this cycle frequency, and after initial testing, it was considered that 50 Hz was a sufficient measurement frequency to capture peak forces. This was further supported by the fact that we used a number of cycles, which further decreased the likelihood of missing peak forces. However, there was a limitation in using a measurement frequency of only 20 Hz in the load cells. Although we were happy that peak forces were not 'lost' as a result of measuring a number of cycles, it would have been safer to measure at 50 Hz. However, the high reliability of both the pressure sensors (peak pressures  $r = 0.945$  test/retest) and the load cells (peak forces  $r = 0.979$  test/retest) support the fact that the measurement frequency was sufficient to capture meaningful data.

It is acknowledged that the correlations between the load cell and pressure measurement data could have been higher in order to confirm the validity of the overall measurement system. However, these correlations were statistically significant which suggests a reasonable relationship between the two measures. In addition two other points must be considered in order to put this into perspective. Firstly, although they can be expected to be related, the load cells and pressure pads were measuring different things, and so a less than perfect correlation between the two measures should be expected. The frictional component of the backpack straps, which was not measured (and would be very difficult to do so), would have affected the load cell forces and the pressure sensors differently. There may have also been small changes in the shoulder areas that were under pressure during different load carriage conditions, which may have led to small differences between the load cell and pressure sensor data.

Most importantly, the results and data sensitivity must be considered within the aims and scope of the study. The results (Tables 1 & 2) of both the load cell and pressure sensor data clearly show that load weight, hip-belt use and shoulder straps clearly had the greatest effects when adjusted. This pattern is clear for both the load cell and pressure sensor data. More detailed claims are not made, and therefore the data collection system has been adequate in providing results that address the original aim of the study.

For each trial the backpack was placed on the mannequin in a standardised manner. This involved firstly placing the backpack on the mannequin and then measuring and re-adjusting the position of the shoulder straps relative to markers on the neck of the mannequin. There were two different positions, depending on whether the ‘tight straps’ or ‘loose straps’ condition was used. This ensured consistency of the position of the shoulder straps relative to the shoulder and the Tekscan pressure sensitive film. The hip-belt was then connected and tightened if it was required. The hip-belt adjustment strap was pulled until the tensiometer read 13.6 kg. This standard tension was used as it represented a force that appeared to add a supportive force to the hips without being overly tight.

Although the hip-belt adjustment was standardised, it must be considered that the compressive properties of the mannequin torso would differ from human torso, which may also have differing support properties. In addition, the similarity between the torso shape of the mannequin compared with school student torso shapes cannot be confirmed. However, it must be remembered that the purpose of the simulator is not to perfectly reproduce human properties, but to provide an initial testing platform prior to more detailed human studies.

## **Results**

For each simulator condition, the ‘overall’ forces and pressures refer to the mean force or pressure over the duration of the data collection period. The ‘peak’ forces and pressures refer to the mean of all of the peak forces which related to each cycle of the simulator) that occurred over the data collection period.

For the purposes of the analysis, all of the data for each load carriage adjustment (ie tight shoulder straps) were grouped together (16 conditions where tight shoulder straps were used), and a further mean and standard deviation was calculated for each load carriage adjustment variable.

# Chapter 4

## *The temporal patterns of schoolbag carriage*

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### **Preface**

In addition to schoolbag design and adjustment, the temporal patterns of schoolbag carriage may also have an effect on the physical demands of schoolbag carriage. The findings of epidemiological literature suggests that exposure to schoolbag carriage may be associated with school student's reported MSD (see review of literature). Despite this, much of the literature addressing responses to schoolbag carriage has focussed on schoolbag weight. Although some studies have exposed school students to a pre-determined duration (typically 20-minutes) of schoolbag carriage, no studies have been carried out under realistic schoolbag carriage conditions. Even more fundamentally, no studies objectively document the temporal patterns of schoolbag carriage that students are likely to experience.

Knowledge of the temporal patterns of schoolbag carriage would allow more realistic replication of schoolbag carriage so that a more realistic assessment of students' responses to schoolbag carriage could then be carried out. In addition, methods used to determine the temporal patterns of schoolbag carriage could be used to detect changes in exposure to schoolbag carriage in future intervention programmes aimed at reducing MSD in school students.

A pilot study (appendix 8) demonstrated that accelerometry could be used to effectively assess the temporal patterns of walking, running and stair-climbing during schoolbag carriage. In the following study, accelerometry was used in conjunction with structured interviews in order to determine the temporal patterns of schoolbag carriage for students in four state schools in Auckland, New Zealand. A paper describing this study has been accepted for publication in a special issue on

'Ergonomics in Schools' of the journal *Ergonomics* and is 'in press'. It is reproduced verbatim as chapter 4 of this thesis.

## Measurement of the temporal patterns of schoolbag carriage using activity monitoring and structured interview

Mackie, H. W. and Legg, S. J. (2004). Measurement of the temporal patterns of schoolbag carriage using activity monitoring and structured interview. *Ergonomics*, In Press.

### Abstract

Although some studies have estimated the total duration of daily schoolbag carriage or the time taken to travel to and from school, no studies have systematically determined the temporal patterns of daily schoolbag carriage. The primary objective of this study was to quantify the temporal patterns of schoolbag carriage over an actual school day using activity monitoring and structured interviews. The secondary objective was to compare activity monitoring and structured interview methods for quantifying daily schoolbag carriage. A Computer Science and Applications Inc. (CSA) activity monitor and structured interview were used to measure, over a 24 hour period, the temporal patterns of 40 student's schoolbag carriage. For each student, the total schoolbag carrying time, mean event schoolbag carrying time and number of schoolbag carrying events was calculated using each method. The total carrying time for students travelling to and from school and the number of students who walked or used transport to travel to and from school were also determined. There were significant correlations between activity monitor [mean(SD) 119(48) minutes] and structured interview [100(39) minutes] determined total schoolbag carrying time ( $r=0.59$ ), activity monitor [8(4) minutes] and structured interview [9(4) minutes] determined mean event schoolbag carriage time ( $r=0.65$ ) and activity monitor [15(4) events] and structured interview [11(2) events] determined number of schoolbag carrying events ( $r=0.52$ ). There was a significant difference between the two methods for the number of schoolbag carrying events ( $p<0.001$ ). Also, for students who used transport, the total amount of time spent travelling to school was significantly greater ( $p=0.02$ ) when measured using the activity monitor [14(12) minutes] than when measured using structured interview [5(10) minutes]. The

durations of schoolbag carriage and the relationship between activity monitor and structured interview were similar to those reported in previous studies. Although not statistically significant, students tended to under-report their schoolbag carriage when compared with activity monitoring.

## Introduction

Schoolbag weight has been the focus of anecdotal concern regarding schoolbag carriage by students, parents and both education and medical professionals. Similarly, literature relating to schoolbag carriage has focussed predominantly on the weight of schoolbags (Negrini et al. 1999, Cheung and Hong 2000, Hong et al. 2000, Whittfield et al. 2001). Furthermore, 10% of bodyweight (BW) has been proposed as an upper schoolbag weight limit (Sander 1979, NBPA 1997), despite a lack of scientific evidence to support it.

Much less attention has been given to the effects of schoolbag design and adjustment and the carrying patterns of schoolbags despite their likely effect on the overall physical demands of schoolbag carriage. However, some studies (Cheung and Hong 2000, Grimmer and Williams 2000, Li et al. 2003) have acknowledged the importance of schoolbag factors other than weight when considering the demands of schoolbag carriage. School student's responses to different schoolbag weights following a pre-determined carriage duration (typically 20-minutes) has been investigated (Cheung and Hong 2000, Hong et al. 2000, Li et al. 2003).

Li et al (2003) studied the effects of carrying 10, 15 and 20% of bodyweight (BW) on trunk posture and respiratory parameters of 15 Chinese boys before and after a 20-minute walk. Although, time alone did not have an effect on trunk posture or respiratory parameters, a mixture of increased load and fatigue following a 20-minute walk was enough to significantly effect trunk posture.

Some epidemiological studies of risk factors associated with back pain or musculoskeletal discomfort (MSD) have shown a positive relationship between schoolbag carriage duration and reported MSD (Negrini and Carabalona 2002, Jones et al. 2003, Sheir-Neiss et al. 2003). In a study of 1269 adolescents (12.9-16.8 years), Grimmer and Williams (2000) demonstrated a positive relationship between time spent carrying a schoolbag to or from school and reported recent low back pain. Longer amounts of time spent carrying schoolbags were strongly associated with low back pain for both boys and girls.

Other studies have reported the traveling times of students walking to and from school (Voll and Klimt 1977, Grimmer and Williams 2000), or durations spent by students carrying schoolbags for parts or all of a school day (Whitfield et al. 2001). Student's traveling time may be related to, but not necessarily the same as, the time spent carrying their schoolbag. Voll and Klimt (1977) found that the average travel time between home and school was 18-minutes for students who used public transport, 25-minutes for those who cycled, 27-minutes for those who were driven to school and 31-minutes for those who walked to school. Grimmer and Williams (2000) found that Year-9 students [mean (standard deviation) 13.8(0.4) years] spent between 11-20 minutes traveling to/from school (girls) or over 30 minutes traveling to/from school (boys). A mean total daily schoolbag carrying time of 99(62.8) minutes for third-form students [13.6(1.3) years] was reported by Whitfield et al. (2001).

In all studies where traveling time or schoolbag carriage duration has been quantified, questionnaires, interviews or diaries have been used to gather data. No studies have used objective measures to quantify the time spent carrying schoolbags, in the field, for an entire school day.

Accurate measurement of schoolbag carriage patterns would allow more sensitive calculations of the relationship between schoolbag carriage and reported MSD in epidemiological studies. In studies of responses to different schoolbag weights, exposure to a realistic pattern of schoolbag carriage would allow more meaningful estimates of upper schoolbag weight limits. Also, in future intervention programmes aimed at reducing MSD in school students, objective measurement of schoolbag carriage would provide a tool for measuring intervention effectiveness.

Activity monitors (which typically include a uni-axial accelerometer) have been successfully used to quantify physical activity in adults (Patterson et al. 1993, Bussmann et al. 1998, Steele et al. 2000) and in children (Janz 1994, Epstein et al. 1996, Puyau et al. 2002). In particular the validity of the Computer Science and Applications (CSA) Inc Activity monitor (now known as the Actigraph Activity Monitor) has been demonstrated (Janz 1994, Melanson and Freedson 1995, Nichols

et al. 2000, Mackie et al. 2004). Using a CSA activity monitor, Janz (1994) found moderate to high ( $r=0.50-0.74$ ) correlations between accelerometry and heart rate telemetry. Nichols et al. (2000) found that acceleration measured using a CSA activity monitor correlated highly ( $r^2=0.89$ ) with oxygen consumption.

Although moderate to high correlations between activity monitoring and heart rate and oxygen consumption have been demonstrated, there will always be a difference between the methods when changes in physical activity occur. An activity monitor will almost instantly detect a change in movement intensity (for example changing from walking to running), whereas heart rate and oxygen consumption measures will change more slowly as the body reacts to the increased intensity by relying more on oxidative energy processes.

Mackie et al. (2004) compared activity monitoring with retrospective video analysis for determining schoolbag carriage patterns. The amount of time spent walking, running and stair climbing while backpacking and when student's donned and doffed their schoolbags was calculated using both a CSA activity monitor and a video camera. An activity monitor was secured within the schoolbags of six 14 year old school students [height 1.54(0.08) m and weight 46.6(8.9) kg] while they completed a predefined physical activity course. Participants firstly completed the course following a set time pattern ('set course') and then repeated the course while performing activities as they pleased ('free course'). The greatest variation between measures was for walking during the 'free course' [8(7) seconds over approximately 2.5 minutes], while the least variation between measures was for stair climbing during the 'set course' [3(2) seconds over approximately 30 seconds]. There were no statistical differences between the activity monitor and video camera determined durations for any of the activities. Although, the CSA activity monitor has been successfully used to quantify the temporal patterns of schoolbag carriage for short durations, it has not been compared with other measures of schoolbag carriage duration for an entire school day.

Questionnaires or diaries are common methods for quantifying daily physical activity and some studies have reported the relationship between questionnaire and

activity monitor determined physical activity. A moderate correlation ( $r=0.46$ ) between self-report and activity monitor measurement of physical activity in 59 obese children [10.5(1.2) years] has been reported (Epstein et al. 1996). Ridder et al. (2002) compared mean weekly physical activity determined using an interviewer-administered questionnaire with vertical body accelerometer movements using a Caltrac accelerometer in 37 schoolgirls [mean 11.2 (Standard error of the mean 0.3) years] and 35 schoolboys [12.1 (0.2) years]. Higher correlations ( $r=0.53$  for girls and  $r=0.59$  for boys) between weight bearing physical activity measured using the questionnaire and activity counts using the activity monitor were reported. Patterson et al. (1993) compared physical activity measurement using an Actigraph activity monitor with 24-hr Self-Report Activity Diary Entries in 15 participants (seven male, eight female) aged 22-57 years. Patterson et al. demonstrated a significant correlation ( $r=0.57$ ) between the average self-reported awake physical activity measured using diaries and that determined from the activity monitor. No studies have compared self-report and activity monitor determined schoolbag carriage duration.

The primary objective of this study was to quantify the temporal patterns of schoolbag carriage for an actual school day using activity monitoring and structured interviews. The secondary objective was to compare activity monitoring and structured interview methods for quantifying daily schoolbag carriage.

## **Methods**

### **Study design**

A cross-sectional study design was used. The schoolbag carrying patterns of school students was measured within participants using activity monitoring and structured interview.

### **Participants**

Forty students [height, weight and age, 1.65(0.06)m, 58.2(14.1)kg and 13.2(0.5) years respectively] comprising five male and five females from each of four secondary schools (five male and five female in each school) were recruited.

Schools were recruited from the Northern, Western, Southern and central areas of Auckland city, New Zealand. Participants volunteered for the study following an advertisement that was announced at their form classes. Ethics approval was granted and informed consent from each participant was obtained prior to the commencement of the study.

## Equipment

A Computer Science and Applications Inc. (CSA) activity monitor was used to measure the temporal patterns of student's schoolbag carriage. The CSA activity monitor is specifically designed for analysing human movement, particularly for measuring daily physical activity and the amount of movement that occurs during sleep. The device is contained within a small plastic matchbox sized case (5.0 x 4.1 x 1.5cm), weighs only 43gms and is robust and splash proof. The activity monitor has an adjustable measurement frequency and is capable of recording for up to 36 hours at 1 Hz. The mechanism used to measure movement is a single channel uni-axial accelerometer that measures acceleration ranging in magnitude from 0.25 to 2.5 G-forces and samples at a maximum of 10 Hz. Output frequencies can range from once every second to once every five minutes. In the present study, a measurement and output frequency of 1 Hz was used as this sampling rate has been shown to be effective for quantifying school student's physical activity (Mackie et al. 2004).

At an initial meeting with each student, the activity monitor was secured within a slot in a foam rubber block (figure 1), allowing the activity monitor to sit securely within the foam rubber. The foam rubber block was then secured within the student's schoolbag at a consistent orientation. The orientation of the activity monitor is important as the accelerometer within it only measures acceleration in one dimension. Deviation from the direction of accelerometer measurement would result in a diminished acceleration signal as a smaller proportion of the movement would occur in the same dimension as the accelerometer measurement.

**Figure 1.** Activity monitor with foam block used to protect and correctly orientate activity monitor within schoolbag.



In addition to the activity monitor data, information was collected at the initial meeting with the student using a structured interview. An interview sheet was used to guide the researcher in obtaining information via a pre-determined interview structure. Students were firstly asked about their, age and whether they used a locker at school.

Subsequent questions guided the researcher to ask students about getting to school (time left home, time arrived at school, percent time items carried, mode of carriage and mode of transport), at school (name and beginning and finish time of each schoolbag carrying event) and getting home (time left school, time arrived at home, percent time items carried and mode of transport).

## Data collection protocol

Exactly the same protocol was followed for each student. The researcher met with each student at an agreed time corresponding with when the student first arrived at school in the morning. The initial interview questions were then completed and student's height and weight (clothed, shoes off) were measured and recorded.

The activity monitor was then activated and placed within the foam rubber block, which was in turn secured within the student's schoolbag. The student was then instructed very clearly not to move or remove the foam rubber block or the activity monitor within their bag or to allow any other person to carry their school bag. The time that the activity monitor was placed in the student's schoolbag was recorded and arrangements were made to meet with the student the following day at the same time.

On the following day the researcher met with the student before school, at the time determined the previous day. Firstly, the activity monitor was removed from the student's schoolbag and the time was recorded. The structured interview was then administered, requiring student's to recall, with the assistance of their school timetable when they carried their schoolbag during the previous day and travelling to school during the same day.

Following the school visit, the data from the activity monitor was downloaded and the information from the structured interview was entered into a spreadsheet. From the activity monitor, a trace of each student's 24-hour schoolbag carrying profile was created and the beginning and finish time of each schoolbag carrying event was determined manually by studying the activity monitor trace.

Before data collection began, the data collection protocol was trialled by three school students who did not participate in the main study in order to ensure successful data collection procedures. The trial data collection protocol demonstrated no problems associated with the structured interview or activity monitor data collection.

## Data processing and statistical analyses

For each student, the total schoolbag carrying time, mean event schoolbag carrying time and number of schoolbag carrying events was calculated using both the activity monitor and structured interview data. Also, the total carrying time for students walking to and from school and number of students who used transport to travel to and from school was calculated. Means and standard deviations were calculated for all results.

The mean absolute difference between the activity monitor and structured interview results were also calculated. The absolute difference was used as results for different individuals were either positive (the results from the activity monitor trace were greater than those determined by structured interview) or negative (the results from the activity monitor trace were less than those determined by structured interview), giving the mean difference for the group a non-sensically low number. By using the absolute difference in results, only the variation and not the sign was considered and a more realistic calculated mean difference between the two methods resulted.

Pearson's linear correlations between activity monitor and structured interview determined total schoolbag carrying time, mean event schoolbag carrying time and number of schoolbag carrying events were carried out. Also, statistical differences between the activity monitor and structured interview determined total schoolbag carrying time, mean event schoolbag carrying time and number of schoolbag carrying events were calculated using univariate analyses of variance (ANOVA). The ANOVA was used to establish whether or not activity monitoring and structured interview methods resulted in similar quantitative outcomes. In addition, ANOVA were used to compare activity monitor and structured interview measures of total carrying time for students walking to and from school and students who used transport to travel to and from school. All statistical analyses were conducted using SPSS version 11.0 (SPSS, Inc., Chicago IL).

## Results

### Total schoolbag carrying time

Total schoolbag carrying time measured using the activity monitor [119(48) minutes] was not significantly greater than total schoolbag carrying time measured using structured interview [100(39) minutes] (table 1). There was a significant correlation ( $r=0.59$ ,  $p<0.001$ ) between the two measures of total schoolbag carrying time (figure 2). The mean absolute difference between total schoolbag carrying time measured using the activity monitor and structured interview was 32(29) minutes.

**Table 1.** Patterns of activity monitor and structured interview determined schoolbag carriage and absolute difference between methods.

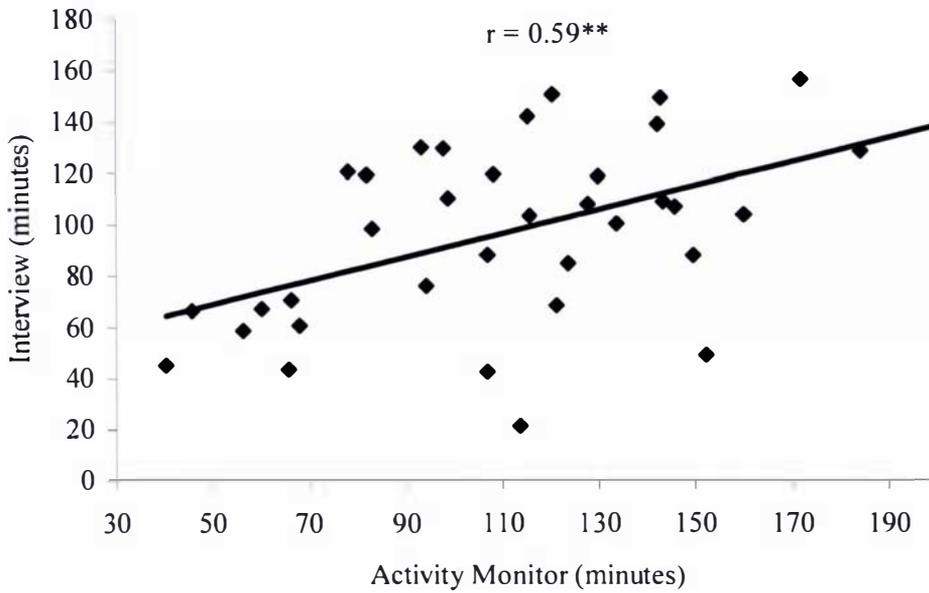
	Total schoolbag carrying time (minutes)	Mean event schoolbag carrying time (minutes)	Number of schoolbag carriage events
Activity monitor	119 (48)	8 (4)	15 (4)
Structured interview	100 (39)	9 (4)	11 (2)***
Absolute individual difference	32 (29)	3 (2)	4 (3)

\*\*\* Difference between methods statistically significant ( $p<0.001$ ).

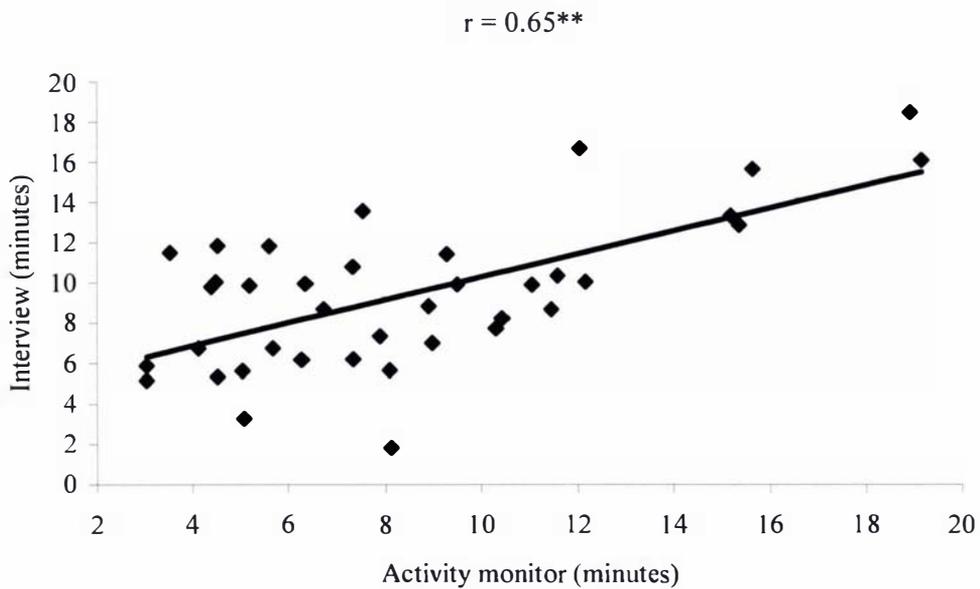
### Mean event schoolbag carrying time

Mean event schoolbag carrying time measured using the activity monitor [8(4) minutes] was not significantly greater than mean event schoolbag carrying time measured using structured interview [9(4) minutes] (table 1). There was a significant correlation ( $r=0.65$ ,  $p<0.001$ ) between the two measures of mean event schoolbag carrying time (figure 3). The mean absolute difference between mean event schoolbag carrying time measured using the activity monitor and structured interview was 3(2) minutes.

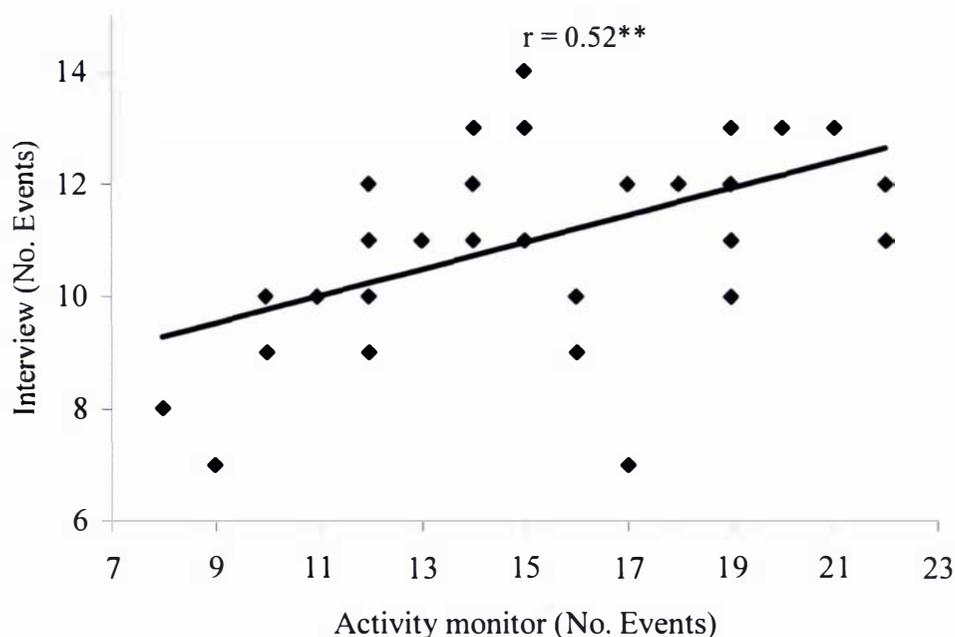
**Figure 2.** Relationship between individual's total schoolbag carrying time determined using activity monitor and structured interview.



**Figure 3.** Relationship between individual's mean event schoolbag carrying time determined using activity monitor and structured interview.



**Figure 4.** Relationship between individual's number of schoolbag carriage events determined using activity monitor and structured interview.



## Number of schoolbag carrying events

The number of schoolbag carrying events measured using the activity monitor [15(4) events] was significantly greater ( $p < 0.001$ ,  $\alpha = 0.05$ ) than the number of schoolbag carrying events measured using structured interview [11(2) events] (table 1). There was a significant correlation ( $r = 0.52$ ,  $p < 0.001$ ) between the two measures of number of schoolbag carrying events (figure 4). The mean absolute difference between the number of schoolbag carrying events measured using activity monitor and structured interview was 4(3) events.

## Travelling to and from school

Travelling to school, more students used public or private transport ( $n = 27$ ) than those who only walked ( $n = 13$ ) (table 2). However, travelling home more students walked only ( $n = 22$ ) compared with those who used public or private transport ( $n = 18$ ).

**Table 2.** Total schoolbag carriage time (minutes) determined using activity monitor and structured interview for traveling to and from school .

Mode of transport	To school		From School	
	Walk (n = 13)	Transport (n = 27)	Walk (n = 22)	Transport (n = 18)
Activity monitor	25 (16)	14 (12)	32 (29)	14 (14)
Structured interview	20 (12)	5 (10)*	26 (17)	11 (14)
Absolute individual difference	8 (6)	8 (6)	14 (26)	9 (13)

\* Difference between methods statistically significant ( $p < 0.05$ )

For students who used transport, the total amount of time spent travelling to school was significantly greater when measured using the activity monitor [14(12) minutes] than when measured using structured interview [5(10) minutes] ( $p=0.02$ ,  $\alpha=0.05$ ). For these students, there were no significant difference between the total amount of time spent travelling home when measured using the activity monitor [14(14) minutes] and when measured using structured interview [11(14) minutes]. For students who walked only, there were no differences between the total amount of time spent travelling to school when measured using the activity monitor [25(16) minutes] and when measured using structured interview [20(12) minutes] or from school when measured using the activity monitor [32(29) minutes] and when measured using structured interview [26(17) minutes]. Although not statistically significant, in all instances except for students who used transport measured using the activity monitor, the mean time spent travelling home was greater than the mean time spent travelling to school (table 2).

## Discussion

The total schoolbag carrying time measured using the structured interview in the present study [100(39) minutes] was very similar to the total schoolbag carrying time for 3<sup>rd</sup> form students [99.9(62.8) minutes] reported by Whitfield et al. (2001). This may be explained partly by both studies being conducted in the same city, using similar methods. However, although not statistically significant, the total schoolbag carrying time was greater when measured using the activity monitor [119(48) minutes], which may suggest that students under-report schoolbag carriage durations.

The significant difference between the number of schoolbag carriage events measured using the activity monitor and the structured questionnaire suggests that students were unable to accurately recall the number of times they carried their schoolbag. Conversely, the similarity of mean event schoolbag carrying time measured using the activity monitor and structured interview suggests that students can more accurately recall the duration of individual schoolbag carriage events.

However, student's ability to recall schoolbag carriage activity appears to vary considerably. The large variation in the absolute difference between activity monitor and structured interview results for total schoolbag carrying time is evidence that some students are able to accurately recall their schoolbag carriage events and event durations accurately, while others appear to have difficulty in doing so.

For students who only walked to or from school, the amount of time spent travelling between home and school (between 20 and 32 minutes) was similar to the amount of time spent travelling between home and school reported by Voll and Klimt 1977 (31 minutes). The results are also comparable to those reported by Grimmer and Williams (2000) where the most common amount of time spent by year 9 students carrying their schoolbags to or from school was 11-20 minutes for girls and over 30 minutes for boys. However, Grimmer and Williams' data did not differentiate between those who used transport to travel to/from school and those who only

walked. Those who only walked may have spent a greater mean amount of time carrying their schoolbags to and from school.

The significant difference between the number of schoolbag carrying events measured using the activity monitor and measured using structured interview may be explained by student's limited ability to precisely recall different schoolbag carriage events. For example, a student might recall one schoolbag carriage event between a class and lunch period, whereas the accelerometer might have detected two carriage events separated by a brief period when the student removed their bag. A student doffing their schoolbag for a brief time that is not associated with the beginning or end of a particular activity or class is unlikely to be recalled, whereas it would be easily detected by the activity monitor.

The correlation between activity monitor and structured interview determined total schoolbag carrying time in the present study ( $r=0.59$ ) was very similar to correlations between activity monitor and questionnaire/self-report reported by de Ridder et al. 2002 ( $r=0.53$  for girls and  $r=0.59$  for boys) and Patterson et al. 1993 ( $r=0.57$ ). Patterson et al. (1993) noted that stronger agreement between activity monitor and activity diary measures was observed for participants who were more detailed in completing their diary entries. This suggests that some of the variation between self-report and activity monitor methods may be a result of a lack of precision in self-reported physical activity and that impressing the importance of accurate information recall on participants would help to maximise the quality of the data.

There are no guidelines for backpacking durations by school-aged adolescents. In adults, there appears to be a consensus that as a general rule of thumb, one third of body weight (or one third of maximal oxygen consumption for a working day) is a maximally acceptable load for average sized, healthy young males (Haisman 1988). However, the adult guidelines are inappropriate for adolescents as significant physiological and biomechanical strain has been demonstrated when 20% of body weight has been carried via a backpack in children or adolescents after a 20-minute walk (Hong et al. 2000, Cheung and Hong 2000, Lai and Jones 2001).

The NIOSH guidelines for manual lifting tasks (Waters et al. 1993) recommends that 40% of baseline maximum aerobic lifting capacity is an upper physiological limit for tasks of 1-2 hours, which is similar to the total durations of schoolbag carriage reported in the present study. Hong et al. (2000) reported working intensities of 40-44%  $\text{VO}_2$  max for school students backpacking with 10-20% of bodyweight after 20-minutes. Initially, it would seem that based on the NIOSH guidelines, the demands of schoolbag carriage can approach adult manual lifting limits. However, the frequent rest periods that school student's experience (on average after 8-9 minutes of schoolbag carriage) means that in reality schoolbag carriage is probably less demanding. In future, guidelines for schoolbag carriage should not only consider the total duration of carriage but also the duration of each carriage event and the frequency of rest periods.

The temporal patterns of schoolbag carriage reported in this study could be used to more realistically assess school student's responses to schoolbag carriage. Using a mixture of school time-tables and the results of this study, a simulated school day could be designed including realistic schoolbag carriage durations and frequencies. This approach would result in more realistic fatigue responses to schoolbag carriage than exposing students to 20-minutes of schoolbag carriage, as has been carried out in previous studies. Alternatively, interventions aimed at reducing student's exposure to schoolbag carriage could use activity monitors to measure the schoolbag carriage patterns and therefore the effectiveness of the intervention.

## **Conclusion**

The durations of schoolbag carriage reported in the present study are similar to those reported previously. In addition the relationship between activity monitor and structured interview determined schoolbag carriage durations were similar to previous studies. Although not statistically significant students tended to under-report their schoolbag carriage when compared with activity monitoring. This appears to be a result of significantly less reported carriage events rather than inaccuracies in estimating schoolbag carriage event durations.

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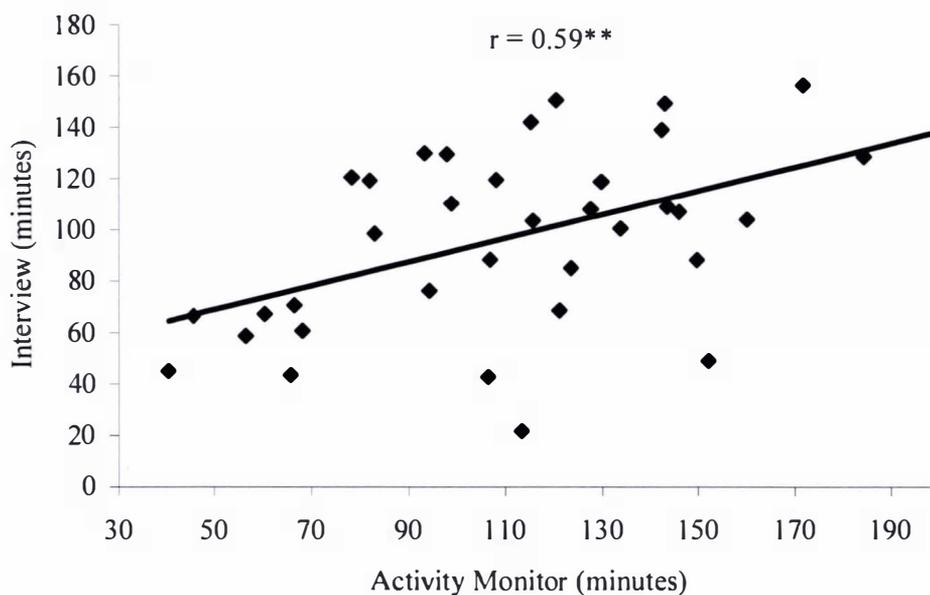
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## Post-script

The following post-script provides details of the published study that require expanding for the doctoral thesis requirements, or explanations of techniques used in response to examiners comments.

### Methods

The primary objective of this study was to quantify the temporal patterns of schoolbag carriage for an actual school day using activity monitoring and structured interviews. The secondary objective was to compare activity monitoring and structured interview methods for quantifying daily schoolbag carriage. The second objective implies that there is an expected similarity between the two methods for measuring schoolbag carriage. It would be reasonable to expect that there would be a linear association between the two measures of schoolbag carriage (activity monitor and interview). The Pearson's correlation reflects the degree of a linear relationship between two variables, and therefore is a suitable procedure for my example. From the example below, although there is lots of variability in the data and the correlation is not strong, one would expect the relationship between the two measures to be linear and not exponential or any other non-linear relationship. The smaller values are clearly related on each axis as are the larger values.



However, it is accepted that for the 'number of carriage events' data a Spearman's rank correlation may have been more appropriate, as this is a non-parametric equivalent of the Pearson's correlation (Harraway 1993 – Introductory Statistical Methods). I carried out a Spearman's rank correlation on 'number of carriage events' data, to check if it resulted in a different output. However, this test provided an outcome that was very similar to the Pearson's correlation outcome (significant at 0.01 level).

In order to determine a statistical difference between the mean 'number of carriage events' it is acknowledged that a non-parametric test such as a Mann-Whitney test (Harraway 1993 – Introductory Statistical Methods) may have been more appropriate than an ANOVA (which is designed for continuous data). I carried this test out on the data. However, again, this non-parametric test revealed a very similar outcome to the ANOVA test that was originally used ( $P < 0.001$ ).

## **Results**

The results of this study refer directly to school bag carriage, which is the focus of this thesis. However, it makes sense to at least consider the implications of lifting and lowering schoolbags. Lifting and lowering (or donning and doffing) a schoolbag occur immediately prior and after a schoolbag carriage event. For example, when a schoolbag is carried, it must be first lifting onto the shoulder(s) and then removed from the shoulder(s) at the conclusion of the carriage event. This means that the temporal patterns of schoolbag carriage (specifically, the number of schoolbag carriage events) that have been addressed in this study, also relate to the temporal patterns of schoolbag lifting and lowering.

# Chapter 5

## ***Schoolbag weight, shoulder strap adjustment and carriage duration***

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### **Preface**

In the first three studies of this thesis, schoolbag design and adjustment were evaluated in laboratory conditions and the temporal patterns of actual schoolbag carriage during school days were quantified. Using the findings of these first three studies, a study was designed to compare student's postural and subjective perceptual responses to five different schoolbag weights and two different schoolbag shoulder strap tightness conditions over a simulated school day.

A standardised schoolbag was chosen based on the aesthetic and functional attributes that students reported as being desirable in chapter 2 (*Schoolbag design*, page 43). Using this schoolbag it was considered most likely that students would attribute their responses to changes in load or adjustment rather than the backpack design itself.

In chapter 3 (*Schoolbag carriage adjustment*, page 68), it was found that schoolbag weight had a significant effect on shoulder forces during simulated load carriage. Therefore, 16 school boys were exposed to different schoolbag weights (0-15% BW) during simulated school days. The findings of chapter 3 also showed that tighter schoolbag shoulder straps (and therefore a higher schoolbag position on the back) resulted in larger forces in the shoulder during simulated load carriage. Because the findings of previous literature in this area are unclear, participants in the present study were also exposed to two schoolbag conditions of equal weight (10% BW) but unequal shoulder strap tightness. The temporal patterns of schoolbag carriage that were quantified in chapter 4 (*The temporal patterns of schoolbag carriage* – page 92) were used to create a realistic template for a simulated school day, to which participants were exposed in a mixed field / laboratory setting.

This study was also carried out in order to achieve the secondary aim of the thesis, which is to obtain objective evidence to assist in determining an upper schoolbag weight limit. A paper describing this study has been submitted to the journal *Ergonomics* for publication. It is reproduced verbatim as chapter 5 of this thesis.

## Postural and subjective responses to realistic schoolbag carriage

Mackie, H. W. and Legg, S. J. (2004). Postural and subjective responses to realistic schoolbag carriage. *Submitted to Ergonomics*.

### Abstract

The objective of this study was to determine school student's postural and subjective self reported responses to different schoolbag weights and shoulder strap tightness, before, during and after a simulated school day and to provide evidence for an upper weight limit for daily schoolbag carriage. Sixteen boys (13-14 years) were exposed to unloaded, 5%, 10%, 12.5% and 15% of body weight (BW) schoolbag carriage conditions. The 10% BW condition was repeated with tightened shoulder straps. The horizontal displacement of body landmarks relative to the ankle joint was used to quantify student's posture. The questionnaire included questions about participant's perceived musculoskeletal discomfort (MSD), exertion, comfort, schoolbag heaviness and difficulty when carrying their schoolbag. Participants were also asked whether they would like to change the schoolbag shoulder strap tightness or weight and were asked of their muscular strain in the shoulders, neck, back, upper and lower legs and pressure on the shoulders and waist and ability to balance and walk while wearing their schoolbag. Posture, RPE and muscular strain and ability to walk and balance were not significantly affected by the duration of carriage or by shoulder strap tightness. However, posture, rating of perceived exertion (RPE) and muscular strain and ability to walk and balance were significantly affected when student's schoolbag load reached 10% BW. Carrying 10% BW induced a significant ( $p < 0.001$ ) change in ear-ankle displacement [mean 4.9(standard deviation 2.9) cm], RPE (3.2,  $p = 0.009$ ) and reported muscular strain and ability to walk and balance (0.8,  $p = 0.004$ ) from the unloaded condition. However, carrying 10% BW resulted in a mean RPE rating of 'fairly light' as opposed to carrying 15% BW which resulted in a mean RPE rating of 'somewhat hard'. The magnitude of self reported measures of muscular strain and musculoskeletal discomfort (MSD) suggested that 15% BW

may be excessive while 10% BW may have been acceptable to participants, which supports a schoolbag weight limit of 10% BW for a typical school day.

## Introduction

Despite widespread anecdotal concern regarding the negative health effects of heavy schoolbags, there is limited guidance for school students, parents and education professionals regarding safe schoolbag carriage. Although guidelines for schoolbag carriage do exist (NBPA 1997), these are not based on any specific evidence. Previously, a regional school council recommended that schoolbags should weigh less than 11% BW (Voll and Klimt 1977) and an orthopaedic doctor has recommended a schoolbag weight limit of 10% of bodyweight (BW) (Sander 1979). Neither of these recommendations were based on specific evidence. An exception is a guidance webpage that has been published by the Government of South Australia government (Government of South Australia, 2004), which is largely based on peer reviewed research (Grimmer et al. 1999, Grimmer and Williams 2000, Grimmer et al. 2002). Part of the South Australian guidelines recommend that carrying a backpack should not significantly alter young people's posture from the side and front view, backpacks should be worn over two shoulders and that the backpack weight should not exceed 10% of the student's body weight (BW). Although there is sufficient evidence to suggest that mode of carriage can affect student's posture (Maholtra and Sen Gupta 1965, Voll and Klimt 1977, Pascoe et al. 1997) there is not yet any conclusive evidence to support an upper recommended schoolbag weight of 10% BW.

In an attempt to provide objective support to schoolbag carriage recommendations, some studies have examined student's physiological (Hong et al. 2000, Lai and Jones 2001, Li et al. 2003) postural (Pascoe et al. 1997, Hong and Cheung 2003, Grimmer et al. 2002) and gait (Pascoe et al. 1997, Wang et al. 2001) responses to schoolbag carriage.

Hong et al. (2000) reported significant differences in blood pressure for loads between 0 and 20% BW and 10 and 20% BW and energy expenditure between 0 and 20% BW. Also, Blood pressure recovery was statistically longer for 15 and 20% BW than for 0% BW, which contributed to Hong et al.'s backpack weight recommendation of 10% BW. Similarly, forced expiratory volume in the first second

(FEV<sub>1</sub>) and forced vital capacity (FVC) were significantly diminished when schoolbag carriage reached 20% BW and also when the students assumed a kyphotic posture (Lai and Jones 2001). Lai and Jones support a schoolbag weight limit of 10% BW due to the fact that no differences in lung volumes were observed between 0 and 10% BW. However, because nothing was reported regarding loads between 10 and 20% BW the evidence provided by this study may be inadequate. Bygrave et al. (2004) found that the tightness of backpack shoulder and chest straps significantly effected lung function in 12 healthy adults.

Despite the previous focus on schoolbag weight, schoolbag adjustment may also affect the user. Using a load carriage simulator, Mackie et al. (2004) demonstrated that in addition to schoolbag weight, the use of a hip-belt, shoulder strap tightness (which in turn determines vertical position on the back) and to a lesser degree load placement within the schoolbag all significantly influenced shoulder forces. Grimmer et al. (2002) demonstrated that a lower backpack position in school students resulted in the least change in posture from an unloaded position.

In adult studies, positioning the load in a backpack near the mid-back rather than just above shoulder level has been shown to decrease erector spinae and upper trapezius muscle activity (Bobet and Norman 1984). Conversely, Bloom and Woodhull-McNeal (1987) suggest that a lower load is closer to the ankles and therefore requires greater forward body rotation in order to maintain stability. Also in support of a high load position on the back, Stuempfle et al. (2004) found that loads carried higher on the back were more energy efficient.

Postural measures have been used to examine responses to schoolbag carriage (Pascoe et al. 1997, Grimmer et al. 2002, Hong and Cheung 2003) based on the assertion that posture that habitually deviates from gravitational alignment may be associated with spinal pain (Grimmer and Williams 2000). Although, angles between body segments have been used to define posture (Pascoe et al. 1997, Grimmer et al. 1999), earlier, Woodhull et al. (1985) proposed a method for defining posture in which the horizontal displacement of body landmarks were measured relative to the lateral malleolus of the ankle joint. This method was subsequently

used to study backpacking in adults (Bloom and Woodhull-McNeal 1987) and schoolbag carriage in children (Grimmer et al. 2002). Measuring the relative horizontal displacement of body landmarks involves less error than measuring angles between body-segments as only two, rather than three points on the body need to be measured.

Questionnaires have also been used to study responses to load carriage. (Legg et al. 1997, Legg et al. 2003, Mackie et al. 2003, Stuempfle 2004). Mackie et al. 2003 found significant differences in musculoskeletal discomfort and preferred backpack when four backpacks that were intended for school use were compared using questionnaires. Legg et al. 1997 and Legg et al. 2003 found that quantitative subjective perceptual and qualitative perceptual methods were effective in distinguishing between backpack designs.

There have been no studies in which school students have been exposed to realistic load carriage durations despite the positive association between carriage exposure and musculoskeletal discomfort (MSD) that has been demonstrated in some epidemiological studies (Grimmer and Williams 2000, Negrini and Carabalona 2002, Jones et al. 2003). If students were exposed to realistic schoolbag carriage conditions then more valid estimates of carriage limits could be determined. The temporal patterns of schoolbag carriage was quantified by Mackie and Legg (2004). Total schoolbag carrying time, mean time for each schoolbag carriage occasion and number of schoolbag carrying occasions were measured using activity monitors and structured interviews. The present study uses this information to expose school students to realistic schoolbag carriage patterns for different loads and schoolbag adjustments in order to more realistically study responses to schoolbag carriage.

The objective of this study was to determine school student's postural and self reported responses to different schoolbag weights and shoulder strap tightness, before, during and after a simulated school day and to provide evidence for an upper weight limit for daily schoolbag carriage.

## Methods

### Study design

An experimental repeated measures study design was used to compare the effects of schoolbag weight, shoulder strap tightness and time of day on body posture and self-reported measures. Each participant was allocated a schoolbag (Billabong day pack, style number: 9211043) (figure 1) that they used for all of the data collection periods. Each backpack contained two identical plastic containers (325 x 125 x 125mm) and a foam pad (350 x 270 x 25mm) which was positioned between the containers and the wall of the backpack closest to the participant's back. The contents of the schoolbags were identical and were positioned identically for all participants. Sand was used to equally fill each container to desired loads. On each day of data collection, each participant carried either no backpack or a backpack loaded to 5%, 10%, 12.5% or 15% BW. An additional experimental condition was included in which a backpack loaded to 10% BW was carried with tighter shoulder straps.

### Participants

Eighteen boys originally volunteered for the study. Sixteen boys [mean (standard deviation) height 161.8(11.5) cm and body weight (BW) 53.1(16.1) kg] aged 13-14 years completed the data collection sessions.

### Data collection tools

Postural data collection involved a modified version of the protocol reported by Woodhull et al. (1985). A Sony Handicam video camera (25 Hz), mounted on a tripod, was placed 4.0m (horizontal distance from the camera lens) from tape on the floor marking the position of the lateral border of the foot closest to the video camera for each participant. Participant's anteroposterior position while standing was aligned with tape placed on the floor and in line with the video camera. Participants were instructed to keep the ends of their toes just inside the tape on the floor.

**Figure 1.** Example of backpack used and joints that were digitised during postural data collection



Joint markers were placed on the ankle (lateral malleolus), knee (mid-way between anterior border of patella and posterior margin of the joint), hip (greater trochanter), shoulder (acromion process) and seventh cervical vertebrae (spinous process). The ear (external canal) and eye (lateral canthus) were also used as landmarks but did not require joint markers. Hip and shoulder joint markers were required to be placed over clothing (figure 1). This did not cause undue error as the participants did not move after the markers were placed. However, to ensure the accuracy of the results, the hip and shoulder markers were only used for descriptive purposes and were not used in statistical analyses.

On each day prior to data collection, a horizontally placed reference stick exactly 1000mm in length was recorded using the video camera in the same plane as the joint markers. The image of the reference stick was subsequently digitised five times and the mean digitised distance was calculated in order to determine a reference scale which was used for calculating distances for all postural measurements. The camera tripod was then taped to the floor and the camera was not moved throughout the duration of data collection.

The reliability of the video analysis protocol was demonstrated by carrying out the video capture protocol and repeating it the following day for twelve participants (13-14 years) independent to the main cohort [mean(SD) height 160.4(8.1) cm and body weight 53.9(14.3) kg]. These participants all carried a load of 7.5 kg, which represented a mean of 14% BW. For the re-test, all body markers were replaced after having been removed the previous day and a measurement scale was re-recorded. This exercise was designed to reproduce the error that would be associated with collecting data on a daily basis. The mean (SD) error (difference between the two days) for all of the body markers was 1.2(1.0) cm. Paired t-test p-values for all body marker errors were all greater than 0.05 probability, indicating that none of the body marker positions were prone to significant variation, including those placed over clothing.

Self-reported data was collected using a questionnaire. In the questionnaire, each student was asked about the region and intensity of any musculoskeletal discomfort that they were currently experiencing for each of 24 body regions (12 front and 12 back) using a regional body diagram (Corlett and Bishop, 1976) and a category ratio scale (CRS) rating method (Noble et al., 1983). Five point scales, where words were associated with the numbers one and five but not the numbers between and where five represented the most strenuous or difficult response were then used. Participants were asked about their comfort and whether the load felt heavy or light while carrying their load and how easy or difficult they thought it would be to carry and lift the load during a school day. Participants were also asked if they would like to change the shoulder strap tightness and if so how and whether they would like to change the backpack load and if so, how. Next, participants were asked to state their

rating of perceived exertion (RPE) for their load and then were asked about their perceived muscular strain in the shoulders, neck, back, upper legs and lower legs, pressure on the shoulders and waist and ability to balance and walk while wearing the backpack.

The reliability of the questionnaire was demonstrated by administering it to the same group of students who were involved in the reliability of the video analysis protocol, after carrying a schoolbag weighing 7.5 kg for 20-minutes around a set course on a level and paved surface. The quantitative test-retest scores were then compared using paired t-tests. The mean (SD) error for the responses to the five point scale questions was 0.2 (0.1) and for RPE was 0.8 (1.3). Comparing between participants for test-retest conditions, there was no significant difference between five point scale or RPE scores ( $p=0.81$ ).

## **Data collection protocol**

Each participant carried one load condition on each of six days. The order was balanced based on the 18 participants that originally volunteered for the study (table 1). Prior to data collection, participant's attended a familiarisation session where they were briefed on the study and allocated schoolbags and participant numbers. Their age (years) height (m) and body weights (kg) were also measured and recorded. Sand was then added to each participant's schoolbag depending on their allocated load condition for day one and was subsequently adjusted at the end of each day for the following day.

On each day of data collection, participants carried their schoolbags according to a simulated school day template (table 2), which was based on the temporal patterns of schoolbag carriage which were reported in a previous study (Mackie and Legg 2004). Participants were exposed to simulated classroom and outdoor activities (morning and lunch intervals and physical education lessons) and walking between classes. Participants were also required to simulate walking to school for 23 minutes and walking home for 28 minutes by walking outside, around a pre-defined course on a level and paved surface. On each day participants carried their schoolbags for a total of 123 minutes with a mean carriage duration of 9 minutes and a total of 15

carriage occasions. All pre-defined walks were ‘set-paced’ by an adult assistant who practiced walking at  $1.0^{-1}$  m.s, using a treadmill, prior to data collection. This pace was used for all pre-defined walks.

**Table 1.** Order of schoolbag carriage conditions for all participants over six days of data collection. Each number represents the percent of bodyweight (% BW) carried for the corresponding day and 10T refers to the 10% BW with tight shoulder straps condition.

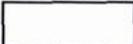
Participant	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	0	10T	5	15	10	12.5
2	5	0	10	10T	12.5	15
3	10	5	12.5	0	15	10T
4	12.5	10	15	5	10T	0
5	15	12.5	10T	10	0	5
6	10T	15	0	12.5	5	10
7	10T	0	15	5	12.5	10
8	Did not complete data collection					
9	12.5	15	10	10T	5	0
10	10	12.5	5	15	0	10T
11	Did not complete data collection					
12	0	5	10T	10	15	12.5
13	0	12.5	10T	10	5	15
14	10T	0	5	12.5	15	10
15	5	10T	15	0	10	12.5
16	15	5	10	10T	12.5	0
17	10	15	12.5	5	0	10T
18	12.5	10	0	15	10T	5

On each simulated school day, data was collected at the beginning, middle and end of the day. During each of the three data collection sessions, the initial musculoskeletal discomfort questions were administered, followed by video data collection. Immediately prior to filming, markers were placed on each participant.

**Table 2.** Template of the temporal patterns for the simulated school day. The shaded times represent schoolbag carriage.

Simulated activity	Time	Duration (min)	Actual activity
	8:15	Arrive	
	8:25	20	Initial data collection
Getting to school	8:45	23	Set-pace walk
Before classes	9:08	11	Outdoor games
Before classes	9:19	6	Outdoor games
Before classes	9:25	4	Waiting to move inside
Getting to form class	9:29	1	Move inside
<b>Form class</b>	9:30	15	Inside activity
Getting to period 1	9:45	4	Set-pace walk
Getting to period 1	9:49	1	Stop set-pace walk
Getting to period 1	9:50	2	Set-pace walk
<b>Period 1</b>	9:52	54	First indoor activity session
Getting to period 2	10:48	6	Set-pace walk
<b>Period 2</b>	10:54	38	Second indoor activity session
<b>Interval</b>	11:32	5	Moving outside
<b>Interval</b>	11:37	13	Outside
Getting to period 3	11:50	5	Set-pace walk
<b>Period 3</b>	11:55	54	Third Activity session (+ data collection)
Getting to period 4	12:49	5	Set-pace walk
<b>Period 4</b>	12:54	43	Fourth activity Session (make and eat lunch)
<b>Lunch break</b>	1:37	16	Outside (free time)
<b>Lunch break</b>	1:53	5	Outside (free time)
<b>Lunch break</b>	1:58	11	Outside (free time)
<b>Lunch break</b>	2:10	16	Outside (free time)
Getting to p5	2:26	3	Set-pace walk
<b>Period 5</b>	2:29	46	Fifth Activity Session
Getting to p6	3:15	8	Set-pace walk
<b>Period 6</b>	3:23	45	Sixth Activity Session
Getting home	4:08	28	Set-pace walk
	4:36	25	Final data collection
	5:00	Home	

**Key**

Carrying schoolbag  Not carrying schoolbag 

Their backpack was then fitted so that the bottom of the backpack was slightly higher than the top of the participant's buttocks. The distance (cm) from the participant's seventh cervical vertebra (C7) to the top of the backpack was then measured and was used to standardise each participant's backpack position on subsequent days. When the tight shoulder straps condition was administered, the distance between C7 and the top of the backpack was 5cm less than the standard position, which allowed a detectable yet not overly restrictive change in schoolbag fit. Participants were then asked to stand in the correct position relative to the tape on the floor while looking "straight ahead". Approximately 8 seconds of video footage was then recorded. Following video data collection, each participant was asked to remain wearing their backpack while they completed the questionnaire.

## **Data processing and statistical analyses**

The video data was digitised using Silicon Coach Digitiser V5 video analysis software. In order to account for postural sway, five frames from the video, at 0.8 second intervals were digitised for each participant and condition. The mean of the five horizontal co-ordinates (pixels) for each landmark was then calculated and converted to length (cm) using the previously determined reference measurement. Horizontal displacement (cm) of each body landmark relative to the ankle joint was subsequently calculated for each load condition and time of day. For statistical purposes, the displacement of the ear, relative to the ankle joint was used to represent each participant's postural change. For load weight and shoulder strap comparisons the data from the end of the day was used and for time of day comparisons the 15% BW load weight data was used.

All questionnaire data was entered into a spreadsheet for analysis. The quantitative questionnaire data (MSD location and intensity, RPE, whether they would like to adjust the backpack or not and perceived muscular strain and ability to balance and walk questions) were summarised while the qualitative data was used to support the quantitative data.

For both the postural and quantitative questionnaire data (except MSD location and intensity), one-way ANOVA were used to compare the residuals for each day of

data collection. There were no statistical differences between data collection days, which indicated no day effect on the data. Repeated measures ANOVA were then used to determine the effects of load and time of day on posture and quantitative questionnaire variables.

Prior to statistical analysis, sphericity (equality of the variances of the differences between treatment levels) of the data was tested using Mauchly's test of Sphericity. If sphericity was not demonstrated, then the Huynh-Feldt correction was applied in order to determine the correct test statistic.

In circumstances where the repeated measures ANOVA resulted in a statistically significant outcome, pair-wise comparisons (paired t-tests) were carried out between all load conditions and the unloaded condition for load and between beginning of the day and both middle and end of the day for time of day. Bonferroni adjustments were applied to the alpha level of significance depending on the number of pair-wise comparisons that were carried out. For statistically significant repeated measures outcomes for load x time of day or strap length (straps) x time of day interactions, pair-wise comparisons were carried out for relative posture (change in posture from unloaded for load and difference between tight and standard strap tightness for straps) between the beginning of the day and both the middle and the end of the day. The shoulder strap adjustment conditions (tight vs loose straps) were analysed separately from the analysis for the different load conditions. Bonferroni adjustments were applied to the alpha level of significance depending on the number of pair-wise comparisons that were carried out.

For the MSD intensity, paired t-tests between conditions for body locations that received a minimum of 8 responses were carried out. SPSS V11.5 statistical software was used for all statistical procedures.

## Results

### Load weight

Load weight had a significant effect on posture ( $p < 0.001$ ), RPE ( $p < 0.001$ ) and reported muscular strain and ability to walk and balance ( $p < 0.001$ ). Subsequent pair-wise comparisons showed that 10% BW was sufficient load to induce a significant ( $p < 0.001$ ) change in posture [mean (standard deviation) 4.9(2.9) cm] from the unloaded condition (table 3). Carrying 15% BW induced a mean change in posture of 6.8(4.0) cm from the unloaded condition.

Posture at the end of the day was strongly positively correlated (pearson's correlation  $r = 0.997$ ) with load (figure 2). In addition, participants tended to respond to the increased load by flexing at the hips. Disproportionately less displacement occurred at the hip joint and the greatest changes in posture occurred approximately equally in the shoulder, C7, ear and eye (figure 2).

A significant increase ( $p = 0.009$ ) in RPE from the unloaded condition [7.2(2.1)] was reached [10.5(3.7)] when 10% BW was carried, representing an RPE rating of 'fairly light' (table 3). Carrying 15% BW induced an RPE of 13.9(3.9) for the group, which corresponds with an RPE rating of 'somewhat hard'. For the 15% BW condition six participants reported an RPE score of 15 or greater, which represents 'hard (heavy)' on the RPE scale (figure 3)

A significant increase ( $p = 0.004$ ) in mean reported muscular strain and ability to walk and balance scores (1-5 scale) from the unloaded condition [1.2(0.3)] was reached when 10% BW was carried [2.0(0.8)] (table 3). Carrying 15% BW induced a score of 2.8(1.0) for the group (figure 4).

The neck/shoulder region was the most common (8 reports) area of the body for reporting musculoskeletal discomfort (table 4). The mean(SD) CRS intensity for musculoskeletal discomfort in the neck/shoulder region when 15% BW was carried was 3.3(1.4) which is between 'moderate' and 'somewhat strong' on the CRS scale.

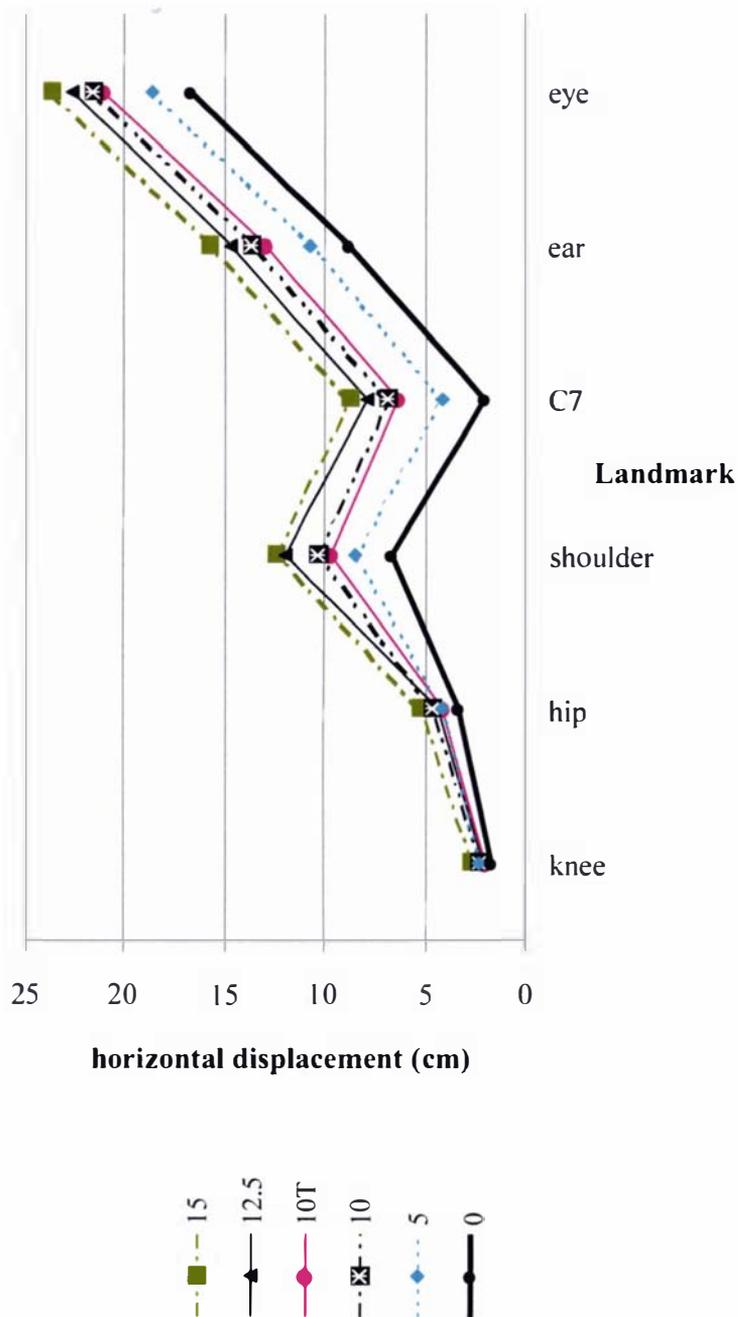
When 15% BW was carried there were two musculoskeletal discomfort reports that had an intensity of five which is associated with ‘strong (heavy)’ on the CRS scale. When asked whether they would like to change the backpack load, one participant for the 5% BW condition, five participants for the 10% BW condition, seven participants for the 12.5 % BW condition and ten participants for the 15% BW conditions reported that they would like the backpack to be lighter at the end of the day.

**Table 3.** Statistical results (p-values) for repeated measures and subsequent t-test comparisons between loads, strap length (straps), time of day and interactions between load and time of day and straps and time of day.

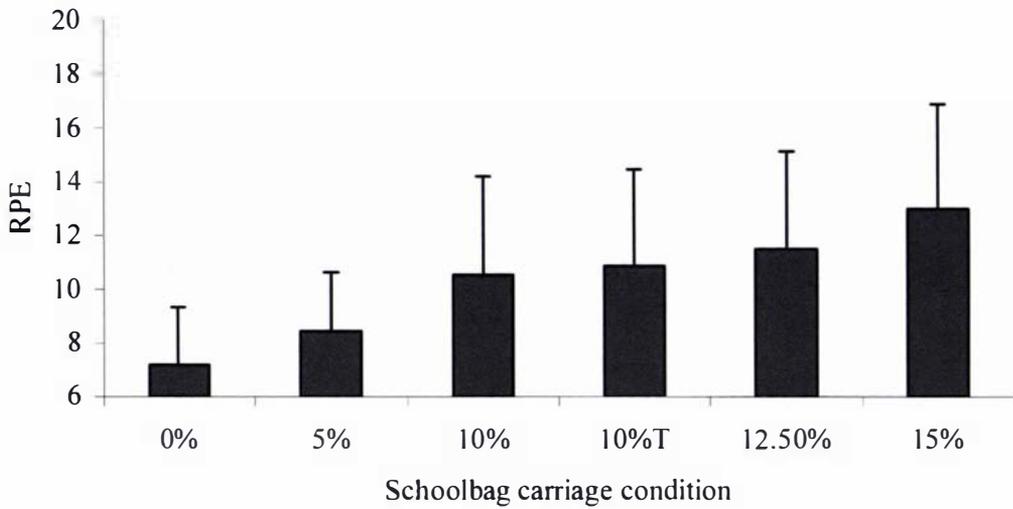
	p-value (repeated measures)	t-test	load stat signif reached	p-value
		$\alpha$ (Bonferroni)		
<b>Load</b>				
Posture	<0.001	0.013	10% BW	<0.001
RPE	<0.001	0.013	10% BW	0.009
Muscular strain	<0.001	0.013	10% BW	0.004
<b>Strap length</b>				
Posture	0.53	n/a	n/a	n/a
RPE	0.69	n/a	n/a	n/a
Muscular strain	0.82	n/a	n/a	n/a
<b>Time of day</b>				
Posture	0.74	n/a	n/a	n/a
RPE	0.37	n/a	n/a	n/a
Muscular strain	0.08	n/a	n/a	n/a
<b>Interactions</b>				
<b>Load x time of day</b>				
Posture	0.01	0.006	5% BW*	0.004
RPE	0.01	0.006	n/a	n/a**
Muscular strain	0.26	n/a	n/a	n/a
<b>Straps x time of day</b>				
Posture	0.29	n/a	n/a	n/a
RPE	0.36	n/a	n/a	n/a
Muscular strain	0.29	n/a	n/a	n/a

- \* p=0.06 was observed for 0 - 10% BW between the beginning and middle of the day  
p=0.07 was observed for 0 - 12.5% BW between the beginning and middle of the day  
p=0.01 was observed for 0 - 15% BW between the beginning and middle of the day  
\*\* p=0.02 was observed for 0-12.5% BW between the beginning and middle of the day  
p=0.04 was observed for 0-15% BW between the beginning and end of the day

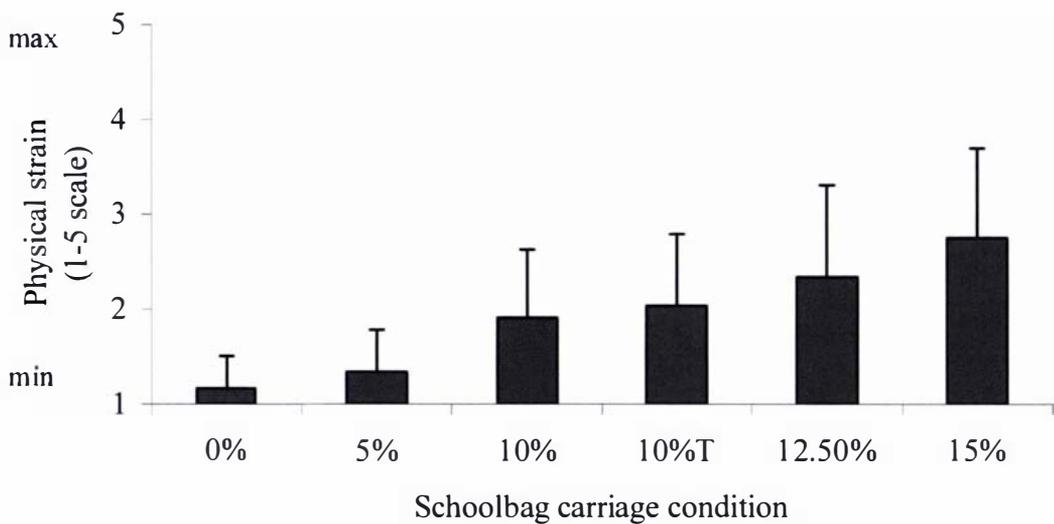
**Figure 2.** Relative mean horizontal displacement (cm) of landmarks to the ankle joint (lateral malleolus) for different schoolbag carriage conditions (0-15% BW and tight (T) shoulder straps) at the end of the simulated school day.



**Figure 3.** Mean (Standard deviation) RPE scores for different schoolbag carriage conditions



**Figure 4.** Mean (Standard deviation) reported strain and ability to walk and balance scores for different schoolbag carriage conditions.



**Table 4.** Counts of reported musculoskeletal discomfort and reported CRS intensity for musculoskeletal discomfort in the neck/shoulder (back) and lower leg (back) regions for 0, 10 and 15% BW at the end (E) and 15% BW at the beginning (B) of the simulated school day.

	0%E		10%E		15%B		15%E	
	counts	mean (SD) intensity						
Neck and Shoulders (Back)	1	2.0 (0.0)	7	1.8 (1.0)	8	2.2 (1.0)	8	3.3 (1.4)
Lower Legs (Back)	9	1.2 (0.4)	7	1.7 (0.9)	4	1.0 (0.7)	2	0.5 (0.0)

## Shoulder strap adjustment and time of day

Neither shoulder strap adjustment or time of day had a significant effect on posture, RPE or reported strain and ability to walk and balance scores (table 3). Although not statistically significant ( $p=0.08$ ), a mean (SD) CRS score of 2.2(1.0) for musculoskeletal discomfort was reported when 15% BW was carried at the beginning of the day compared with 3.3(1.4) at the end of the day (table 4).

When asked whether they would like to change the shoulder strap adjustment, four participants for the 10% BW tight shoulder straps condition reported that they would like to loosen the shoulder straps. For the standard 10% BW condition two participants reported that they would like to tighten the shoulder straps.

## Load x time of day and straps x time of day interactions

Load x time of day interactions were observed for posture ( $p=0.01$ ) and RPE ( $p=0.01$ ) but not muscular strain (table 3). Pair-wise comparisons revealed that only

a change of load from 0 – 5% BW between the beginning [1.4(1.6) cm] and middle [4.3(3.1) cm] of the day was sufficient to alter posture with an alpha level of 0.006 as a result of the Bonferroni adjustment. Although not significant with an alpha level set at 0.006, a change in load from 0 – 10% BW ( $p=0.06$ ), 0-12.5% BW ( $p=0.07$ ) and 0-15% BW ( $p=0.01$ ) between the beginning and middle of the day had marginal effects on posture.

No pair-wise comparisons revealed significant changes in RPE (table 3). However, although not significant, with an alpha level set at 0.006 a change in load from 0 – 12.5% BW ( $p=0.02$ ) and 0-15% BW ( $p=0.04$ ) between the beginning and middle of the day had marginal effects on RPE.

There were no significant interactions between shoulder strap adjustment and time of day.

## **Discussion**

### **Load weight**

The main finding was that load weight significantly affected posture, RPE and muscular strain and ability to walk and balance when the load carried reached 10% BW. Based on these results and the rationale that posture that deviates from normal is more likely to cause MSD (Grimmer and Williams 2000) it could be argued that carrying 10% BW is more likely to cause MSD than carrying no load or 5% BW. However, for the purposes of determining a weight limit for schoolbag carriage, the postural results alone do not indicate a limit as although the change in posture was directly proportional to weight carried, there was no disproportional change in posture at any given weight that might indicate a disproportional increase in physical strain. This finding is very similar to the proportional relationship between schoolbag weight and postural adjustment reported by Grimmer et al. (2002). It is more likely that carrying 15% BW is the most likely condition to cause MSD as it caused the greatest change in posture.

The RPE and muscular strain and perceived ability to walk and balance results, together with the postural results provide a basis for determining an upper schoolbag carriage limit. Carrying 10% BW resulted in a mean RPE score which related to 'fairly light' whereas carrying 15% BW resulted in a mean RPE score which related to 'somewhat hard'. In addition, six participants carrying 15% BW rated the load as 'hard (heavy)' on the RPE scale. The RPE results suggest that carrying 10% BW was not strenuous for the participants whereas carrying 15% BW was.

Furthermore, although a statistically significant increase in perceived muscular strain and ability to walk and balance questions was reached when 10% BW was carried, the mean score was only 1.2 on a 1-5 scale, again indicating that carrying 10% BW was not excessively strenuous in this study. Despite the mean score of 2.8 for the 15% BW condition being not excessive on a 1-5 scale, the distribution of the data (SD 1.0) meant that many of the participants reported overall scores closer to the most strenuous or difficult end of the 1-5 scale.

The perceived stress of carrying 15% BW was further supported by the CRS scale results. The 'moderate' to 'somewhat strong' musculoskeletal discomfort reported by some participants could be considered excessive when it is considered that students carry their schoolbags for approximately two hours each day (Mackie and Legg 2004).

Additionally, the qualitative questionnaire results showed that when 15% BW was carried, ten of the sixteen participants reported that they would like to lighten the load, whereas only five participants reported this when 10% BW was carried. This adds to the evidence that carrying 15% BW was considered to be materially more strenuous for the participants than carrying 10%BW.

Overall, the questionnaire based results suggest that although carrying 10% BW was associated with a statistically significant increase in many measures, the participants did not report their load as being perceived as strenuous until they carried 15% BW. When combined with the postural results, it could be argued that 15% BW is excessive for schoolbag carriage.

The findings of this study differ slightly from the statistically significant changes in physiological (Hong et al. 2000, Lai and Jones 2003) measures that have been reported between unloaded and schoolbag weights of 20% BW. The fact that 10% BW was sufficient to invoke significant postural and self reported responses in the present study may be because the participants had a greater mean body weight than in the participants used by Hong et al. 2000, Lai and Jones 2003. Participants in the present study carried schoolbags that were heavier and might have perceived equal relative loads to be heavier than smaller school students might perceive and therefore responded accordingly. However, further work would need to be carried out to account for the lack of evidence for this in the present or previous studies.

### **Shoulder strap tightness and time of day**

The results of the present study differ from those of Grimmer et al. (2002) and Mackie and Legg (2004) in that tightening the shoulder straps had no effect on posture, RPE, or reported muscular strain and ability to walk and balance. Grimmer et al. (2002) found that a lower backpack position (which is made possible by more looser shoulder straps) resulted in a smaller change in posture from unloaded. One reason for the differing results may be that the ranges of backpack placement used in Grimmer et al.'s study was much greater than that used in the present study, meaning that greater effects on posture would be more likely. Mackie et al. (2004) found that shoulder strap forces and pressure increased when tight rather than loose shoulder straps were adopted. This might mean that although shoulder strap forces increase with tighter shoulder straps, the changes used in the present study (5cm difference in schoolbag position) might not be sufficient to change posture or cause participants to detect differences in MSD.

The lack of a time of day effect on posture, RPE and muscular strain and ability to walk and balance suggests that carrying loads of up to 15% BW are not enough to invoke postural or perceived responses from participants over a school day. It may have been that the rest periods to which participants were exposed, were sufficient to allow them to recover. These findings support those of Hong and Cheung (2003),

who found no difference in gait patterns and trunk posture between the beginning and end of a 1892 m walk for schoolbag loads of up to 20% BW.

Conversely, many epidemiological studies have demonstrated an association between schoolbag carriage duration or exposure and reported MSD (Grimmer and Williams 2000, Negrini and Carabalona 2002, Jones et al. 2003). These results may suggest that the mechanism for developing MSD as a result of schoolbag carriage might occur cumulatively over a long period of time. Only a longitudinal intervention study would determine whether this is true or not.

## **Load x time of day interactions**

The significant and marginally significant load x time of day interactions between the beginning and middle of the day are difficult to interpret as the effect did not get stronger as load increased. In fact the 5% BW condition between the beginning and middle of the day resulted in the only significant change in posture. Much of the load x time of day interactions that were observed for posture can be attributed to a change in unloaded posture between the beginning and middle of the day. None of the other load conditions demonstrated such changes, which may mean that carrying a load in a backpack forces the wearer into a posture that accommodates the extra load on the back. In the absence of such a load, student's standing posture might vary more as they have more control over how they wish to stand.

## **Conclusion**

Posture, RPE and muscular strain and perceived ability to walk and balance were significantly affected when student's school bag load reached 10% BW. However, posture, RPE and muscular strain and perceived ability to walk and balance were not significantly effected by the duration of carriage over a school day for loads of up to 15% BW or by shoulder strap tightness. The magnitude of self reported measures of muscular strain and MSD as a result of carrying 10% and 15% BW suggests that carrying 15% BW may be excessive, which supports a schoolbag weight limit of 10% BW for a typical school day.

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# Chapter 6

## ***Schoolbag weight: a psychophysical approach***

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### **Preface**

In chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration* page 119), posture, RPE and muscular strain and perceived ability to walk and balance were significantly affected when student's schoolbag load reached 10% BW. However, the magnitude of self reported measures of muscular strain and MSD suggests that carrying 15% BW may be excessive and carrying 10% BW is acceptable to school students. These findings support a schoolbag weight limit of 10% BW for a typical school day.

In the review of literature, Snook's psychophysical method for determining upper weight limits for manual handling was briefly described. Using Snook's methodology, participants are given control over the weight of the load being lifted. Participants are asked to work as hard as they can on an incentive basis "without straining or becoming unusually tired, weak, out of breath or overheated". Participants carry out the task firstly with a very light load, to which they add weight and then with a very heavy load from which they remove weight. The mean of the two final chosen weights is then calculated to determine the maximum acceptable weight of lift (MAWL). In this chapter, a final study is described in which Snook's psychophysical method was modified in order to determine a maximum acceptable schoolbag weight (MASW).

The advantage of the psychophysical approach is that an actual estimate for a MASW can be determined. This is a more direct approach than the methods that have been used in any previous schoolbag study. The disadvantage is that the method is purely subjective and therefore it would be beneficial to seek supportive evidence with independent objective measures.

A paper describing this study has been submitted for publication in the journal *Applied Ergonomics*. It is reproduced verbatim as chapter 6 of this thesis.

## A psychophysical approach to determining an upper schoolbag weight

Mackie, H. W., Legg, S. J. and Walt, S. E. (2004). A psychophysical approach to determining an upper schoolbag weight. *Submitted to Applied Ergonomics*.

### Abstract

No studies have demonstrated conclusive evidence for an upper schoolbag weight limit despite 10% of bodyweight (BW) being commonly recommended by medical and education professionals. The objective of this study was to determine a maximum acceptable schoolbag weight (MASW) using a psychophysical approach. Snook's (1978) psychophysical methodology was modified to allow for the adjustment and evaluation of schoolbag weight. Sixteen boys [mean (standard deviation) height 160.8(11.9) cm and weight 52.1(16.5) kg] aged 13-14 years simultaneously completed a 20-minute data collection session whereby they repeatedly adjusted and evaluated their schoolbag weight. Sand was added or removed from plastic containers which were positioned within participant's schoolbags prior to a walk around a set course while wearing their schoolbags. The overall mean relative MASW (as a percentage of BW) was 10.4(3.8) kg which is very similar to the commonly recommended schoolbag weight limit of 10% BW and supports objective results from previous studies. Although other schoolbag, school and personal factors also need to be considered, based on this psychophysical approach, 10% BW is recommended as a MASW.

Keywords: manual handling, load carriage, student

## Introduction

A variety of methods have been used to study school student's responses to schoolbag carriage. School student's physiological (Hong et al. 2000, Lai and Jones 2001, Li et al. 2003), postural (Pascoe et al. 1997, Hong and Cheung 2003, Grimmer et al. 2002) and gait (Hong and Cheung 2003, Pascoe et al. 1997, Wang et al. 2001) responses to schoolbag carriage have been studied. However, no studies have demonstrated conclusive evidence for an upper schoolbag weight limit despite 10% of bodyweight (BW) being commonly recommended by medical and education professionals.

Part of the lack of conclusiveness regarding an upper schoolbag weight limit might partially be a result of the measures that have been used to study responses to schoolbag carriage. Objective measures such as gait, posture, heart rate and oxygen consumption have assisted in identifying the relationship between schoolbag carriage weight and changes in participant's physical response. However, no studies have recommended a schoolbag weight limit as a consequence of changes in objective measures resulting from carrying increased schoolbag weight. Mostly, statistical changes in objective measures have been used to determine when carrying a given schoolbag load causes a physical adaptation when compared with an unloaded condition. Significant changes in physiological (Hong et al. 2000), postural (Grimmer et al. 2002, Hong and Cheung 2003) and gait (Pascoe et al. 1997) measures have been reported between unloaded conditions and schoolbag weights of 15-20% BW. However, Mackie and Legg (2004) demonstrated statistical changes in posture and subjective measures once 10% BW was carried.

Questionnaires, including five point, RPE and CRS scales have also been used to study responses to load carriage (Legg et al. 1997, Legg et al. 2003, Mackie et al. 2003). Legg et al. (1997) found that a quantitative self perceptual approach was effective in distinguishing between backpack designs while Legg et al. (2003) found that qualitative self perceptual measures were more effective in distinguishing between backpack designs. Mackie et al. (2003) found significant differences in

musculoskeletal discomfort and preferred backpack design when four backpacks that were intended for school use were compared using questionnaires.

The use of RPE and CRS scales allow the conversion of numerical data into qualitative statements such as “somewhat hard” or “very hard”. When applied to different schoolbag weights these scales provide a more direct measure of schoolbag weight acceptability than statistical changes in objective measures such as posture or gait. Mackie and Legg (2004) found that carrying a schoolbag weight of 15% BW resulted in a mean RPE score of 13.9 which corresponds with ‘somewhat hard’ as opposed to carrying a schoolbag weight of 10% BW which resulted in a mean RPE score of 10.5 which corresponds with ‘fairly light’.

An even more direct method of obtaining evidence for a maximum schoolbag weight is to use a psychophysical approach. This subjective method has been used extensively in manual materials handling research (Ayoub and Dempsey 1999, Morrissey and Liou 1988, Snook 1999, Haslam et al. 2004) along with physiological and biomechanical approaches in determining workload limits. The psychophysical approach assumes that over an adjustment time of 40 minutes, a person can predict their maximum comfortable weight that they can lift for an 8 hour period.

The psychophysical approach to determining a maximum acceptable lifting weight was developed by Snook and Irvine (1966). This methodology was chosen as some of the lifts were infrequent and involved small muscle groups, making measurements of heart rate and oxygen consumption, which had been used previously (Snook 1965), inappropriate. Nine male participants (age 25-37 years, mean 30.1 years) were instructed to lift a wooden box once every fifteen minutes for three different lifting heights. Participants adjusted the weight of the box with loose lead shot using a scoop. The study recommended that 52 lb was the maximum acceptable weight that 90% of the male industrial population should lift. This was in agreement with a previous Swiss study (International Occupational Safety and Health information Centre 1962) that recommended that 50 lb is the maximum weight of a compact object that should be lifted by unselected, adult male workers based on the amount of stress imposed on the spinal discs. Tables giving the

maximum weights that are acceptable to 10, 25, 50, 75 and 90% of the working population are presented in tables (Snook and Ciriello 1991) based on seven studies by Snook and his colleagues of lifting, lowering, pushing, pulling, carrying and walking. Evidence of a link between the demands of lifting and the incidence of injury (reported low back pain) was suggested in a study by Snook et al. (1978) that involved a follow-up postal survey of 161 back injury cases. It was suggested that a worker carrying out a task that is acceptable to only 75% of the population is three times more likely to be injured than if the task were acceptable to everyone.

Using Snook's methodology, participants are given control over the weight of the load being lifted. The experimenter controls other aspects such as the height and frequency of lift. The workers are then asked to work as hard as they can on an incentive basis "without straining or becoming unusually tired, weak, out of breath or overheated". Participants carry out the task firstly with a very light load, to which they add weight and then with a very heavy load from which they remove weight to determine a maximum acceptable weight of lift (MAWL). The mean of the two MAWL's is then calculated to determine a maximal acceptable weight.

Despite the differences between industrial and schoolbag lifting and carrying, this methodology could easily be modified to determine an estimate for a maximum acceptable schoolbag weight. This would significantly add to current evidence supporting a recommended upper schoolbag weight. Thus, the objective of this study was to determine a maximum acceptable schoolbag weight (MASW) using a psychophysical approach.

## **Methods**

An experimental cross-over study design was used. Sixteen boys [mean (standard deviation) height 160.8(11.9) cm and weight 52.1(16.5) kg] aged 13-14 years completed the data collection session.

Snook's (1978) psychophysical methodology was modified to allow for the adjustment and evaluation of schoolbag weight. Each participant was assigned their

own station which included a schoolbag with foam padding (Billabong day pack, style number: 9211043), tray of dry sand, scoop, funnel and two identical plastic containers (figure 1). All equipment was identical between participants, and participants familiarised themselves with the equipment prior to data collection.

**Figure 1.** Apparatus at each participant's data collection station.



Prior to data collection each participant was asked to adjust the shoulder straps of their schoolbag to a length which they felt was most comfortable. The distance (cm) between the spinous process of each participant's seventh cervical vertebrae and the top, anterior margin of their schoolbag was then measured. Tape was then placed around the adjustment buckle of each shoulder strap to prevent adjustment and students were asked not to remove the tape or adjust their shoulder straps at any time during data collection. Participant's height and weight (clothed, no shoes) was then measured and recorded.

In order to maintain consistency between participants, data collection was carried out for all participants as a group, simultaneously. Prior to data collection, two supervisors in addition to the main researcher were briefed on the data collection protocol and were used to maintain consistency between participants during the data collection period.

Participants were then randomly divided into two groups of eight participants. In the first group each participant's plastic containers were empty ('start empty'). In the second group each participant's plastic containers were equally filled to the top with 12 kg of sand from their sand tray ('start full'). This was the maximum weight of sand that could be fitted into the plastic containers. It was also considered that no participant would find this weight acceptable and therefore would need to remove at least some sand from the containers. Prior to data collection, the first group was instructed to begin by adding sand to their containers and the second group was asked to begin by removing sand from their containers.

At the beginning of the data collection session, participants were instructed with the following statement, which is a modified portion of instructions used by Snook (1978):

***“Add or remove sand equally from the containers until you reach the maximum load that you could carry and lift in your backpack for the duration of a typical school day, including walking to and from school, without straining yourself or becoming unusually tired, weakened, overheated or out of breath”***

Participants were then instructed to begin adjusting the sand in their containers equally, place the containers in their schoolbags and then wear their schoolbag to assess its weight over a two-minute period (table 1). After two minutes all participants were led on a four-minute walk around a set course (total 240m, 40 stairs) which involved walking along corridors and up and down stairs within a university campus building. This course was the same as that used by Mackie and Legg (2004a) when participants were lead on a set-paced walk lasting four-minutes. Following this walk, participants arrived back at their data collection stations. The

adjustment/evaluation process was repeated two more times before participants adjusted the weight in their schoolbags to a final weight. The total adjustment/evaluation process took 20 minutes. In total four adjustment periods were included.

**Table 1.** Schoolbag weight adjustment protocol

Time	Activity
0-2 min	Initial adjustment of weight to desired load
2-6 min	Walk on set course to evaluate load
6-8 min	Re-adjust weight to desired load
8-12 min	Walk on set course to evaluate load
12-14 min	Re-adjust weight to desired load
14-18 min	Walk on set course to evaluate load
18-20 min	Final re-adjustment of weight

Although Mackie and Legg (2004) have shown that the mean schoolbag carriage time over a school day is 8-9 minutes and that school students carry their schoolbags on average 11-15 times during the course of a day, there are occasions when school students tend to carry their schoolbags for shorter durations and at higher frequencies. The findings of Mackie and Legg (2004) were used to design a simulated school day Mackie and Legg (2004a), which included higher frequency (1-5 minutes) and short duration (1-6 minutes) schoolbag carriage occasions. The carriage durations and frequencies chosen for the present study were chosen partially to represent these higher frequency carriage occasions and partially for practical reasons such as the time required for students to adjust the weight of their backpacks.

Following the schoolbag weight adjustment exercise, all participants were asked to leave the room while each schoolbag was weighed. Ten minutes after the end of data collection, the process was repeated, but with the first group starting with full containers and the second group starting with empty containers.

An unpaired t-test was used to check for an order effect for the mean difference between ‘start empty’ and ‘start full’ schoolbag weight between those who began data collection with ‘start empty’ and those who began with ‘start full’ containers. The schoolbag weight data was then sorted into ‘start empty’ and ‘start full’ groups and a paired t-test was used to check for differences between the means for each group. For each participant, the difference between their ‘start empty’ and ‘start full’ schoolbag final weights, the mean of the two final weights and the mean weight as a percentage of BW was calculated. Finally, the mean absolute final weight was calculated for the group as the relative maximum acceptable schoolbag weight (MASW).

## Results

Table 2 shows the results of the weights chosen to be carried by the participants when they started with either the empty or full schoolbag. The mean weight of the ‘start empty’ schoolbag was 5.0(1.6) kg and the mean weight of the ‘start full’ schoolbag was 5.2(1.9) kg. There was no order effect in the two starting conditions and there was no statistical difference between the mean final weights in the two conditions. The mean individual difference between the ‘start empty’ and ‘start full’ schoolbag weights was 0.9(1.2) kg and the overall mean absolute schoolbag weight was 5.1(1.7) kg. This corresponds to a mean carriage load of 10.4(3.8) %BW.

**Table 2.** Mean(SD) ‘start empty’ and ‘start full’ MASW, mean individual difference between ‘start empty’ and ‘start full’ weights, average of ‘start empty’ and ‘start full’ weights and average weight as a percentage of bodyweight. n=16.

	Start low (kg)	Start high (kg)	Mean individual difference (kg)	Average	% of bodyweight
mean	5.0	5.2	0.9	5.1	<b>10.4</b>
standard deviation	1.6	1.9	1.2	1.6	<b>3.8</b>

## Discussion

The MASW that was determined in the present study (10.4% BW) is very similar to the 10% BW that has been commonly held as a recommended upper schoolbag weight. The results also support Mackie and Legg (2004) who reported that carrying 10% BW was considered ‘fairly light’ by school students as opposed to carrying 15% BW which was considered ‘somewhat hard’. This may indicate that a load of 10% BW is considered acceptable while a higher load of 15% BW is not. In the present study the standard deviation of 3.8% BW indicates that most student’s MASW was less than 15% BW, which also suggests that for the group, carrying 15% BW would feel too heavy.

Using postural, gait and physiological measures, previous studies (Grimmer et al. 2002, Hong et al. 2000, Hong and Cheung 2003, Mackie and Legg 2004, Pascoe et al. 1997) have found that carrying schoolbags that weigh between 10-20% BW are sufficient to invoke statistically significant physical responses. The results of the present study suggests that a load of 10% BW, while not necessarily invoking a

physical response, may represent a threshold in the physical demands of schoolbag carriage.

The results of this study do not indicate that school students are more likely to be injured when carrying more than 10% BW. Only a large scale, controlled, longitudinal study of school students carrying varying schoolbag weights would indicate a true MASW for the purposes of injury prevention. In addition, other aspects of schoolbag carriage such as schoolbag design, schoolbag adjustment and mode of carriage have been shown to affect student's responses (Grimmer et al. 2002, Mackie et al. 2003, Pascoe et al. 1997) to schoolbag carriage and must also be considered when attempting to relate schoolbag use to musculoskeletal injury. Furthermore, non-schoolbag factors such as locker use, previous injury, developmental stages and psychosocial factors also need to be considered.

The advantage of using the psychophysical approach in determining a MASW is that it is very direct. No other method has an actual schoolbag weight as a dependent variable. However, its main limitation is that it is a subjective method and that there known relationship between chosen weight and risk of injury in school aged children. Additionally, the psychophysical approach has not previously been used with children, where issues of growth and development may be important.

A number of studies report that the psychophysical methodology is not appropriate for high and low frequency lifting tasks (Ciriello and Snook 1983, Karwowski and Yates 1984). Karwowski and Yates (1986) studied seven female college students lifting at frequencies of 1, 3, 6 and 12 lifts per minute, each for four-hour tasks. At 15-minute intervals the students were asked about their degree of confidence (DOC) regarding the weight they believed they could lift for an eight hour day. The weights chosen at 30 minutes did not differ from those chosen at four hours for frequencies of 1, 3 and 6 lifts per minute, while the 12 lifts per minute weight was 23% lower at 4 hours than at 30 minutes. It was concluded that the psychophysical method should not be used for lifting frequencies greater than 6 lifts per minute. Although this is a commonly stated limitation of the psychophysical approach, it would not apply to the present schoolbag example as the schoolbag lifting frequencies of school

students would definitely be much less than 6 lifts per minute and certainly more than an infrequent lift.

The MASW that has been determined only pertains to the frequency of carriage and walking speed that was used in this study. Since the carriage frequency and walking speed were designed to simulate realistic schoolbag carriage, a MASW of 10.4% BW could be considered as real as can be accomplished in a laboratory setting.

Only boys were used as participants in the present study and so the findings are not directly applicable to girls. However, at ages 13-14 years the difference in physical capability between boys and girls is unlikely to be great. A further study including girls should be carried out in the future.

## **Conclusion**

Using a psychophysical approach, a mean maximum acceptable schoolbag weight of 10.4% BW for 16 school boys was determined. The results of this study support the commonly recommended schoolbag weight limit of 10% BW.

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# Chapter 7

## *Discussion*

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### **Introduction**

The purpose of this chapter is to discuss and compare the findings of the five studies that were carried out with each other and with the literature. The thesis aim will be central to this discussion. The specific results of each study have already been discussed within each chapter.

The effects of schoolbag design and adjustment, carriage duration and schoolbag weight on students' responses to schoolbag carriage will be discussed. The influence of schoolbag weight on students' responses to schoolbag carriage will extend into a discussion of the evidence that exists to support an upper schoolbag weight limit.

The limitations of the research and recommendations for future research will also be discussed along with considerations for the development of schoolbag carriage guidelines. Lastly, the thesis conclusion will be stated.

### **The effects of schoolbag design, adjustment, carriage duration and weight on students' responses to schoolbag carriage**

The aim of this thesis was to examine the effects of schoolbag design, adjustment, carriage duration and weight on students' responses to carrying schoolbags. A secondary aim was to obtain objective evidence to assist in determining an upper schoolbag weight limit.

In the following discussion, the effects of schoolbag design and adjustment, carriage duration and schoolbag weight on students' responses to schoolbag carriage will be discussed individually in further detail with respect to the previous literature. The

current evidence that exists to support an upper schoolbag weight limit will also be discussed.

## Schoolbag design

The findings of chapter 2 (*Schoolbag design*, page 49) suggest that school students' preference of backpack may change between when they first examine a prospective backpack and after 20-minutes of walking. The study also shows that school students' preferred attributes in a backpack may shift over this time from 'style and image' to 'function and fit'. This suggests that schoolbags should be both appealing to school students and functionally well designed. Backpacks that are functionally well designed but not aesthetically pleasing might not be used in the first instance, which would prevent the backpack's functional benefits from being appreciated. It was also found that backpack design affected school students' RPE, perceived muscular strain in the back, pressure on the shoulders, balance, ease of walking and musculoskeletal discomfort after a 20-minute walk.

Previously, fundamentally different backpack designs have been compared only in adult studies. Externally and internally framed backpacks (Bloom and Woodhull-McNeal 1987, Kirk and Schneider 1992) and front-back and backpack designs (Kinoshita 1985, Cook and Neumann 1987, Lloyd and Cooke 2000) have been compared. More recent studies of backpack design testing (Bryant et al. 2001, Reid et al. 2004, Stevenson et al. 2004) suggest that subjective perceptions, performance testing and more sophisticated kinematic and kinetic analyses are the most appropriate tools for comparing backpack performance. It would seem advisable that future schoolbag designs could be evaluated using the more sophisticated mixed methodology approach that has been used in recent adult studies.

The results of the present study are similar to the findings of previous adult studies (Legg et al. 1997, Legg et al. 2003) in that subtle backpack design differences could be distinguished by participants using subjective perceptual methods, including CRS and RPE scales and questions about their musculoskeletal discomfort. However, the present findings are the first to demonstrate that these measures can be used with school students.

Although it has been demonstrated that schoolbag designs can be compared using subjective perceptual methods, fundamentally different schoolbag designs have not been compared. Anecdotally, many students do not use hip-belts or waist-belts despite their existence on most schoolbag designs. The development of a schoolbag that does not include a hip-belt, yet is still capable of removing much of the schoolbag weight from the shoulders, is an example of a design that would cater for the specific needs of school students. Such a schoolbag could then be compared with others using the design evaluation protocols that have been described in this thesis.

These findings are not only important for backpack design evaluations. The fact that a backpack design affected students' reported MSD meant that in subsequent studies in this thesis of backpack adjustment, carriage duration and weight, it was important to standardise the design of the schoolbags.

## Schoolbag adjustment

The adjustment of schoolbag shoulder strap tightness and hip-belt use was shown to affect shoulder strap tension forces and shoulder interface pressure during simulated schoolbag carriage (chapter 3 – *Schoolbag carriage adjustment*, page 77). Although load placement within a backpack did not have a significant effect, logic would suggest that placing heavy objects closer to the user's back is likely to lessen the burden experienced, due to the reduced torque acting on the shoulders. Arranging the load in a backpack vertically using partitions within the main compartment has been shown to result in significantly less shoulder, neck, lower back and overall perceived discomfort (Jacobson et al. 2003). This method of arranging the load within a backpack would have the same effect as minimising the distance between the load centre of mass and the person's back.

Despite the finding that looser shoulder straps resulted in less force and pressure at the shoulder during simulated schoolbag carriage, the findings of previous studies are less clear. Bygrave et al. (2000) found that wearing a backpack (15 kg) with a tight chest strap and hip-belt resulted in decreased expired air in the first second of expiration, which could restrict a person's ability to breathe and in turn affect performance. Although these findings focus on a person's ability to breathe rather

than the forces applied to the shoulders, they are in agreement with the present findings in that a looser backpack fit appears to be more optimal.

Shoulder strap tightness also affects the vertical placement of the backpack on the back. Tighter shoulder straps mean that a backpack is worn higher on the back than when looser straps are used. The optimal vertical position of loads carried on the back has been studied (Bloom and Woodhull-McNeal 1987, Bobet and Norman 1984, Grimmer et al. 2002, Stuempfle et al. 2004), but the findings are inconclusive. A lower backpack position has been shown to decrease erector spinae and upper trapezius muscle activity (Bobet and Norman 1984) and reduce postural adjustment to a backpack load (Grimmer et al. 2002). These findings are in agreement with the present simulator findings in that looser shoulder straps (and therefore a lower backpack position) would be preferable. Conversely, Bloom and Woodhull-McNeal (1987) suggest that a lower load requires greater forward body rotation in order to maintain stability. Also, Stuempfle et al. (2004) showed that  $VO_2$ , VE and RPE were all significantly lower when a backpack load was placed higher on the back and suggested that items packed higher on the back may be the most energy efficient load position.

Unfortunately, the effects of shoulder strap tightness (and therefore vertical backpack placement) in the present findings are also inconclusive. In contrast to the findings of chapter 3 (*Schoolbag carriage adjustment*, page 77), the findings of chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 132) showed that shoulder strap tightness (5cm difference in vertical backpack position) had no effect on postural and self-reported responses. However, the magnitude of the change in shoulder strap tightness may have been insufficient to enable participants to differentiate between shoulder strap settings. Using a similar methodology, Grimmer et al. (2002) found that for backpacks positioned at T7, T12 and L3 (vertebrae), less postural adjustment was required when the backpacks were positioned at L3 on the backs of school students. These variations in backpack positions (T7-L3) are much greater than 5cm, which was used in the present study and may have accounted for the more positive findings.

The difference between the simulated and human findings regarding shoulder strap tightness highlights a critical difference between simulated and actual schoolbag carriage. While the simulator was able to detect force differences between backpack adjustments, the simulator results gave no indication of whether the magnitude of the force differences were sufficient to become problematic or even be detected by humans. However, good predictive agreement was found between skin contact pressures, strap forces and relative displacement of a backpack with respect to a mannequin on the simulator and subjective evaluations of the same backpack following field trials in adults (Bryant et al. 2001). It may be that simulator results are predictive of adult responses in military situations, but not of school students' postural and self-reported responses.

## The temporal patterns of schoolbag carriage

This study is the first to assess the temporal patterns of schoolbag carriage by direct measurement rather than by retrospective recall. In chapter 4 (*The temporal patterns of schoolbag carriage*, page 108) it was reported that the temporal patterns of schoolbag carriage in the present study are similar to those reported previously (Voll and Klimt 1977, Grimmer and Williams 2000, Whitfield et al. 2001). Students carried their schoolbags for 119 minutes each day when measured using accelerometry and 100 minutes each day when assessed using structured interview. The mean schoolbag carrying time was 8 minutes (accelerometry) and 9 minutes (structured interview). The mean number of schoolbag carriage occasions was 15 (accelerometry) and 11 (structured interview). The similarity of the present results with previous findings provides retrospective validity to previous research.

These schoolbag carriage patterns were used to develop a simulated school day, to which 16 boys (13-14 years) were exposed to schoolbag carrying conditions of 0, 5, 10 and 15% BW and 10% BW with loose and tight shoulder straps (chapter 5 – *Schoolbag weight, shoulder strap adjustment and carriage duration*, page 124). The findings of chapter 5 suggest that exposure to realistic schoolbag carriage patterns over a day are insufficient to cause changes in postural and self-reported measures of strain and musculoskeletal discomfort for loads of up to 15% BW. In addition, based on the NIOSH guidelines, the demands of schoolbag carriage can approach adult

manual lifting limits (see limitations and recommendations for future research in this chapter). However, the frequent rest periods that school students' experience (on average after 8-9 minutes of schoolbag carriage) means that in reality schoolbag carriage is probably less demanding than what is portrayed when compared with the NIOSH guidelines.

In chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 138) it was also noted that the present findings differ from those reported in epidemiological studies where an association between load carriage exposure or carriage duration and reported back pain has been reported (Negrini and Carabalona 2002, Jones et al. 2003, Grimmer and Williams 2000, Viry et al. 1999, Sheir-Neiss et al. 2003, Siambanes et al. 2004). This might mean that the mechanism for developing back or neck pain as a result of schoolbag carriage might occur cumulatively over a long period of time. Therefore, much greater durations between measures (weeks or months) would have been required in order to detect the effects of backpack carriage duration on posture or reported MSD. These findings might also mean that the type of injuries likely to result from schoolbag carriage are 'overuse' type injuries resulting from cumulative micro-trauma over a long period of time, as opposed to acute injuries that are more likely to result from a single event of high loading. This is reinforced by the findings of Wiersema et al. (2003) who analysed injuries relating to emergency department visits throughout the United States and found that 89% of acute backpack injuries did not involve the back. Instead, 22% involved the head/face, followed by the hand (14%), wrist/elbow (13%), shoulder (12%) and foot/ankle (12%). Backpack injuries involving the back may develop over a long duration and are unlikely to require visits to emergency departments and therefore were not detected by Wiersema et al..

Over longer periods of time, school students may also have more time to be exposed to other risk factors such as sports involvement and the psychosocial influences of family and friends. For example, if a mother or father is more likely to commonly report of musculoskeletal pain or discomfort, then this may have an effect on a school student's tendency to report pain or discomfort. Also, if a student commonly reports pain in other areas of the body i.e. headaches, then they may be more likely

to complain of back or neck pain. These have also been identified as being associated with reported back pain in school students (Balague et al. 1995, Jones et al. 2003, Van Gent et al. 2003). The development of back pain is likely to be multifactorial, with schoolbag carriage being only one of many factors associated with reported back pain (Brackley and Stevenson 2004, Grimes and Legg 2004, Trevelyan and Legg 2004).

## Schoolbag weight

Schoolbag weight adjustment had the most significant effect on shoulder forces and pressure of all the schoolbag adjustment factors using a load carriage simulator (chapter 3 – *Schoolbag carriage adjustment*, page 78). Increasing the load from 10% BW to 15% BW resulted in a 50% increase in overall shoulder strap tension, 36% increase in peak shoulder strap tension, 70% increase in overall shoulder interface pressure and 65% peak shoulder interface pressure.

These findings prompted closer examination of the effects of schoolbag weight in human participants. Following a simulated school day, posture, RPE, muscular strain and perceived ability to walk and balance were significantly affected when students' schoolbag load reached 10% BW. These findings are consistent with those of Li and Hong (2004), who reported that dynamic posture (trunk inclination angle) was significantly increased, from an unloaded condition, when 10% BW was carried by 12 year old school students. Previously, significant changes in physiological measures have been reported between unloaded and loaded schoolbags weighing 20% BW (Hong et al. 2000, Lai and Jones 2003).

In chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 135), participant's mean forward postural adjustment was shown to increase by 39% when schoolbag weight increased from 10% BW to 15% BW. This is similar to the shoulder strap tension findings in chapter 3 (*Schoolbag carriage adjustment*, page 79). In addition, greater muscular strain and musculoskeletal discomfort was reported. Also, twice as many participants reported that they would like to lighten their schoolbag when 15% BW was carried compared with 10% BW. The findings in both of these chapters suggest that increasing schoolbag weight from 10% BW to

15% BW is likely to be associated with a detectable increase in the physical demands placed on the user.

The magnitude of self reported measures of muscular strain and MSD in chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 137) suggests that carrying 10% BW was perceived as reasonable by participants, whereas carrying 15% BW was considered excessive. This supports the findings of chapter 6 (*Schoolbag weight: A psychophysical approach*, page 155) where a psychophysical approach demonstrated that a mean (SD) of 10.4(3.8) %BW was considered to be a maximum acceptable schoolbag weight (MASW) for school students. Collectively, these studies support an upper schoolbag weight of 10% BW for 13-14 year old school students. This represents a refinement of the upper schoolbag weight limit of 10-15% BW that has been proposed based on previous literature (Brackley and Stevenson 2004). Carrying 15% BW represents a load which is likely to cause complaint among students and exceeds most students' MASW, determined using the psychophysical approach.

Some previous studies have also suggested that 10% BW represents an appropriate upper weight limit for schoolbag carriage (Sander 1979, Voll and Klimt 1977), despite a lack of specific evidence to support such recommendations. The present findings are in agreement with the recommendations of these studies. This may be a coincidence, or alternatively, previous recommendations may have been based on practical, but subjective, observations and represent a reasonable estimate of an appropriate upper schoolbag weight. If this were the case, it is unfortunate that objective evidence was not gathered to support the recommendations.

## Summary

The findings of this thesis demonstrate that schoolbag factors other than schoolbag weight have an effect on school students' self-reported and simulated responses to schoolbag carriage. Schoolbag design had an effect on school students' preferred backpack, RPE, reported strain in the back and pressure on the shoulders before and after 20-minutes of use. Simulated schoolbag carriage demonstrated that schoolbag hip-belt use and shoulder strap adjustment had a significant effect on shoulder strap

tension and shoulder interface pressure. However, shoulder strap tightness and carriage duration had no effect on students' standing posture, RPE, reported muscular strain and perceived ability to walk and balance.

Of all the schoolbag factors, schoolbag weight had the greatest effect on shoulder strap tension and shoulder interface pressure during simulated schoolbag carriage. In addition, standing posture, RPE, reported muscular strain and perceived ability to walk and balance were all significantly affected by schoolbag weight.

Although posture, RPE, muscular strain and perceived ability to walk and balance were all significantly affected when 10% BW was carried, the magnitude of self-reported muscular strain and MSD as a result of carrying 10% compared with 15% BW, suggests that carrying 15% BW may be excessive. Using a psychophysical approach, a maximum acceptable schoolbag weight of 10.4% (SD 3.8) BW was determined. Based on these findings a schoolbag weight limit of 10% BW is supported.

The findings of this thesis represent the first systematic attempt to use a mixture of both objective and subjective measurements to study student's responses to changes in schoolbag design, adjustment, carriage duration and weight. The findings of this thesis also support the view that 10% BW is a realistic upper schoolbag weight limit for students.

## **Limitations and recommendations for future research**

The major limitation to the present findings is that only short-term responses to schoolbag carriage have been examined. There was intentionally no attempt to associate schoolbag factors with long-term MSD in the study designs as only a large scale, case controlled longitudinal epidemiological study would be effective in achieving this. However, such a study would not have allowed detailed examination of the effects of different schoolbag factors on school students' responses, as was achieved in the present studies. Accurately controlling schoolbag design,

adjustment, carriage patterns and weight on such a large and long-term scale would be almost impossible.

Consequently, the long-term effects of carrying more than 10% BW on reported MSD is still unknown. Although some previous epidemiological studies have demonstrated a relationship between schoolbag weight and reported back or neck pain (Negrini et al. 1998, Viry et al. 1999, Grimmer and Williams 2000, Sheir-Neiss et al. 2003, Korovessis et al. 2004, Siambanes et al. 2004), none have demonstrated that carrying more than a certain weight increases the likelihood of back or neck pain. The findings of Van Gent et al. (2003) are almost an exception to this. A p-value of 0.06 resulted from an analysis of variance (ANOVA) for the percentage of 745 school students who carried less than 10% BW reporting neck/shoulder complaints, compared with those who carried between 10% and 18% BW. This finding might be considered ‘marginally significant’ and is the closest epidemiological finding to supporting a schoolbag weight limit of 10% BW.

The only way to definitively determine whether carrying more than 10% BW is more likely to cause MSD would be to reproduce the methodology used in chapter 5, with the exception of using a much greater sample size and much greater exposure periods (years rather than a day). However, this approach would most likely be deemed ethically unacceptable and would certainly be entirely impractical.

It is unknown whether the evidence to support a schoolbag weight limit of 10% BW is applicable to other age-groups. The age range for school students in all of the studies included in this thesis is 12-14 years. This age is when school children are carrying the heaviest loads relative to their body mass (Grimmer et al. 1999, Whitfield et al. 2001), which may be putting them at increased risk of developing MSD. Li and Hong (2004) found that a six-year-old group of students carrying loads of 15% BW and 20% BW caused a statistically significant change in trunk posture compared with unloaded. In contrast, for a 12-year-old group, 10, 15 and 20% BW caused a statistically significant change in trunk posture compared with unloaded. The greater mean trunk inclination angle demonstrated by the 12-year-old group

may have been due to the heavier absolute loads that they were carrying, compared with the 6-year-old group.

The finding of Li and Hong (2004) is consistent with a possible trend in the raw data from chapters 5 (appendix 14) and 6 (appendix 16). In both instances, it appears that a given relative schoolbag weight felt less demanding for smaller students than for their heavier counterparts. From chapter 5 (appendix 14), the RPE scores for the seven lightest participants (seven rather than eight due to missing data) were compared with those of the eight heaviest participants for the 10% BW / end of the day condition. The mean (SD) RPE for the seven lightest participants was 9.1(4.1) which correspond approximately with 'very light' on the RPE scale. The mean (SD) RPE for the eight heaviest participants was 11.8(3.0) which sits between 'light' and 'somewhat hard' on the RPE scale. In chapter 6 (appendix 16), the maximum acceptable schoolbag weights of the eight lightest participants were compared with those of the eight heaviest participants. The mean (SD) maximum acceptable schoolbag weight for the eight lightest participants was 11.2(3.8)% BW, while the mean (SD) maximum acceptable schoolbag weight for the eight heaviest participants was 9.9(3.6)% BW.

Although neither of these differences is likely to be statistically significant, similar comparisons with a greater number of participants may confirm that lighter (or younger) school students perceive any given relative load as being less demanding than heavier students. This may mean that using % BW to compare backpack weights between individuals is over-simplistic and a more sophisticated method of determining a relative schoolbag weight may be required. This may also mean that recommending a single maximum schoolbag weight as a percentage of BW is over-simplistic. However, the psychophysical findings demonstrate that the variations between light and heavy students' maximum acceptable schoolbag weight is unlikely to be large. A useful topic for future study would be to compare the physical capabilities of different sized school students of the same or of different ages. Further study in this area might also investigate the effects of the adolescent growth spurt on the backpack carrying / lifting capabilities of students. This sudden acceleration of growth might mean that for a period of time, student's schoolbag

handling capability is deceptively low, especially if loads are measured as % BW. Although their weight will have increased as a result of the growth spurt, their physical strength may not have increased proportionately.

Using mean and standard deviations for MASW's may also be over-simplistic. Although these summary statistics are consistent with those used in previous studies (Pascoe et al. 1997, Hong et al. 2000, Wang et al. 2001 and Hong and Cheung 2003) it must be considered that the mean represents a load that is acceptable to 50% of participants. Originally, Snook and Irvine (1966) recommended a maximum acceptable weight that 90% of the male industrial population should lift. However, if the psychophysical results from chapter 6 (*Schoolbag weight: A psychophysical approach*, page 155) were to be interpreted in a similar way, a MASW for 95% of students in the study would only be 2.4 kg. It would be impractical to recommend a MASW of 2.4 kg as this would equate to carrying a schoolbag and some lunch and no more. If this weight were to be used as a maximum recommended schoolbag weight, it would be quickly rejected by most students as it represents a completely impractical limit. The relatively large variation in the psychophysical results may have resulted from differences between participants perception of a 'maximum acceptable schoolbag weight'. To some students, any weight might be considered unacceptable compared with carrying no weight, while other students may have considered quite heavy loads as 'acceptable' as the load may be similar to what they normally carry. Despite this, the quantitative and qualitative results of this thesis, along with those of previous studies suggest that 10% BW is currently the best estimate of a practical schoolbag weight limit for school students. Thus, 10% BW is a 'practical' recommended weight limit, although it needs to be recognized that this may only offer protection to 50% of the population.

Furthermore, many schoolbag carriage studies have been conducted using Chinese school students (Hong et al. 2000, Lai and Jones 2001, Wang et al. 2001, Hong and Cheung 2003, Li et al. 2003, Li and Hong 2004). The participants used in these studies were smaller and lighter than the predominantly Caucasoid/Maori/Pacific Island participants used in the present studies. Comparing the physical capabilities of Chinese, Caucasoid, Maori and Pacific Island students would also be useful.

The limitations of applying adult limits to children are demonstrated by the findings of chapters 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 132) and 6 (*Schoolbag weight: A psychophysical approach*, page 155). In these chapters, the evidence to support a schoolbag carriage weight limit of 10% BW is very different to the commonly recommended adult load carriage limit of one third of body weight. Some of this difference may be attributed to the more systematic examination of different backpack loads in the present studies compared with studies that have contributed to adult backpacking weight limits. If the methods used in this thesis were applied to adults, then the backpack weight limit for adults might be considerably less.

There has been no differentiation between lifting and carrying schoolbags in the present studies. In chapter's 5 and 6, students were required to both lift and carry their schoolbags and the effects of the combined effort of performing both was studied. A computer programme exists (Arbor 1986) that allows three dimensional static strength predictions for manual handling tasks based on an algorithm derived from a collection of strength studies described by Chaffin and Andersson (1984). Although it is designed for adults, estimates for the relative risk associated with lifting a schoolbag could be carried out using the computer programme.

Data that represented a typical schoolbag lifting scenario were used in the strength prediction computer programme. A male of 162 cm and 53 kg was used as it represented the mean height and weight data from chapter 5 (*Schoolbag weight, shoulder strap adjustment and carriage duration*, page 124). A load of 15% BW (92 N) applied to one hand was used as it represented the heaviest load from chapter 5. A lifting posture that incorporated 45 degrees of trunk flexion, 20 degrees of axial rotation, 20 degrees of lateral bending, upper leg angle of 135 degrees (from right horizontal) and lower leg angle of 80 degrees was used. These angles were estimated from video footage of schoolbag lifting by the participants from chapter 5 that had been captured earlier. Using these input data, the estimated compression force at the L5/S1 joint was 2206 N, which is 65% of the back compression design limit (BCDL) of 3400 N. This exercise would suggest that lifting a schoolbag of 15% BW

in a typical manner is unlikely to cause lower back injury. However, the model does not account for the upward acceleration of the backpack, which would add to the compressive force in the spine, nor the possible relative weakness of a student of 13 years compared with an adult. If a load of 30% BW (approximation of the adult load carrying limit) is used in the computer programme, then the estimated compression force at the L5/S1 joint is  $3051 \pm 224$  N. When the effect of acceleration is added, lifting a load of 30% BW may produce a back compression force that exceeds the BCDL and may therefore mean that the person is at risk of injury. This exercise provides some evidence that the adult load carrying limit of one third of BW is inappropriate for school students. If lesser schoolbag loads do not represent an injury risk during lifting, it may mean that the mechanism for MSD as a result of carrying schoolbags is related to long-term changes in posture as a result of carrying, rather than the occasional peak forces associated with lifting.

The developers of the static strength prediction program are clear in pointing out that it should be used as a first approximation of measuring lifting strain and it should not be used in isolation to evaluate manual handling tasks. Further limitations of the program include approximating posture based on varying body types and postural preferences and the inability of the program to distinguish between the variety of objects that are likely to be handled and foot / floor interfaces that may be encountered in manual handling situations.

In chapters 5 and 6 only boys were included as participants. This means that the results are not directly applicable to girls. However, during adolescence, the difference between boy's and girl's body mass is negligible and so the results may also be applicable to girls of this age. Nevertheless, further work involving female participants is required in order to determine their specific responses to schoolbag carriage.

It is acknowledged that there are other aspects of school students' lives that may also contribute to the development of back or neck pain. Some studies have shown that there is a mismatch between the dimensions of school furniture (chair/desk) and the anthropometric characteristics of school students (Parcells et al. 1999, Legg et al.

2003). This may have an effect on students' susceptibility to developing back or neck pain although a direct link between MSD and school furniture design has not been demonstrated. Also, none of the students who participated in the present studies had access to lockers while at school. If a student were able to store their belongings in a locker while they attended school, their schoolbag would generally weigh less, as would the duration spent carrying their belongings. The effects of locker use on schoolbag weight and duration of carriage has not been studied. Research in this area would assist in identifying the role of lockers in reducing the schoolbag demands on students.

Future research might also focus on evaluating the effectiveness of procedures that schools implement in order to manage the risk factors that may be associated with MSD in school students. The implementation of procedures and guidelines within schools represents the practical application of current research findings and may be one of the most important steps in reducing MSD in school students. The guidelines that have been developed by the Government of South Australia (Government of South Australia 2002) is the first example of this.

## **Considerations for the development of schoolbag carriage guidelines**

There is a need for the development of interventions aimed at reducing students' exposure to the risk factors present in a school environment (Trevelyan and Legg 2004). Because there is evidence to suggest that schoolbag weight may be associated with back pain in students (Negrini et al. 1998, Viry et al. 1999, Grimmer and Williams 2000, Sheir-Neiss et al. 2003, Korovessis et al. 2004, Siambanes et al. 2004), it would be prudent to include schoolbag carriage guidelines within wider risk management interventions.

It could be argued that it is inappropriate to recommend a maximum schoolbag weight as it has been demonstrated that schoolbag design, adjustment and carriage duration also affect the demands placed on students. However, it would be impractical not to recommend a maximum schoolbag weight as this would offer no

guidance to students. Instead, a recommended maximum schoolbag weight should be supplemented with recommendations for schoolbag design, adjustment and carriage duration. Likewise, it would be impractical to recommend a very low maximum schoolbag weight (2.8 kg) in accordance with what was acceptable to 95% of participants in chapter 7. A more practical recommendation would be the 50<sup>th</sup> percentile load of 10% BW, supplemented with advice recommending that this load is highly subjective and that there are many other factors such as physical fitness, previous injury and other schoolbag factors which might mean that an individual's recommended load might be lower or higher than 10% of BW.

There are some practicalities associated with schoolbag carriage that mean that students are required to carry a given load regardless of their size. For example, most students will require their lunch, sports gear, text books, stationery and possibly a computer or musical instrument throughout the day, and the weight of these items are unlikely to be significantly affected by a student's size. This would mean that there may be some merit in recommending an absolute load that students should carry (for example 5 kg) based on a practical representation of their typical schoolbag contents. However, this would be a re-active approach to determining weight limits. A more pro-active approach would be to maintain a recommended MASW of 10% BW as it would require students, parents and schools to make planning changes which would lead to the reduction of loads in some cases, rather than forcing smaller students to carry relatively large loads.

Sometimes backpacks are slung over one shoulder when carried by students. Although this might represent a risk to students carrying their belongings due to the asymmetrical nature of the loads they are carrying, it has been shown that most students carry their backpacks over two shoulders. Whitfield et al (2001) showed that 70% of New Zealand school students in their study carried their backpack over two shoulders. Likewise, Grimmer and Williams (2000) found the over two thirds of students carried their schoolbag over two shoulders. Despite these positive findings, it is clear that a minority of students carries their schoolbag over one shoulder, and advice against this practice should be included in load carriage recommendations. However, although intuitively asymmetric load carriage may seem undesirable, and

single handed schoolbag carriage has been associated with increased MSD (Viry et al. 1999), more studies have shown no relationship between schoolbag carriage mode and reported MSD (Korovessis et al. 2004, Pucktree et al. 2004, Siambanes et al. 2004).

In addition, it might be appropriate to recommend that a more comprehensive suspension system be used in schoolbag designs if loads greater than 10% BW are to be carried. Most students do not use properly designed hip-belts when carrying their schoolbags and therefore hip-belts were not used by participants in the present studies to provide evidence for an upper schoolbag weight. If a well designed backpack with sufficient padding and a good hip-belt were used, then students may be able to carry a little more than 10% BW without causing undue strain or fatigue.

The effects of shoulder strap adjustment and schoolbag carriage duration on posture, RPE, muscular strain and perceived ability to walk and balance were inconclusive in the present studies. Previously, shoulder strap tightness has been shown to affect posture (Grimmer et al. 2002) and schoolbag carriage duration has been shown to affect reported MSD (Grimmer and Williams 2000, Negrini and Carabalona 2002, Jones et al. 2003, Sheir-Neiss et al. 2003). Therefore, more research should be carried out in these areas before recommendations about them can be made.

Individual's fitness, or history of previous injury may also affect students' schoolbag carriage capability and MSD but have not been addressed in the present series of studies. These factors should also be considered when developing guidelines for schoolbag carriage. It might be that more physically conditioned school students or students who are practiced in carrying their schoolbags are more capable of carrying a given load compared with less physically conditioned students. Furthermore, a previous back injury might predispose students to further MSD and prevent them from carrying their schoolbag. Alternatively, appropriate schoolbag carriage might provide necessary strengthening for a previously weak and injury prone back. Further work addressing the implications of previous injuries for schoolbag carriage would provide evidence for recommendations in this area.

Finally, it must be considered that schoolbag carriage may be an important component of school students' physical activity, especially as childhood inactivity and obesity are becoming increasingly problematic. School students should not be discouraged from carrying their schoolbags and recommendations for schoolbag carriage should emphasize the health benefits of schoolbag carriage. A focus on distinguishing between 'unsafe' and 'healthy' schoolbag carriage might be more appropriate than simply outlining the possible dangers associated with schoolbag carriage. Furthermore, schoolbag carriage guidelines could promote a minimum duration of schoolbag carriage per week in order to promote physical activity among students. It appears that no studies have examined the effects of schoolbag load on students' daily energy expenditure or physical well-being, despite the fact that schoolbag carriage is an integral part of most student's lives. Most studies of children's daily physical activity and energy expenditure levels have focused on the temporal patterns of physical activity (Janz 1994, Epstein et al. 1996, Puyau et al. 2002) without considering the intensity of students' physical activity. The contribution of schoolbag load to daily physical activity intensity levels would be a useful area of research as it would address an important, yet neglected, factor in measuring school students' physical activity.

Commuting to and from school is potentially a source of students' daily physical activity (Ziviani et al. 2004) and has often been neglected in studies of children's physical activity (Tudor-Locke et al. 2002, 2003). In chapter 4 (*The temporal patterns of schoolbag carriage*, page 107), it was reported that students who walk to school spent approximately 25 minutes walking to school and 32 minutes walking home. This means that some students may spend approximately one hour walking each day while carrying their schoolbag. For a given walking pace, carrying a schoolbag would be associated with an increased exercise intensity and could possibly proffer health benefits.

Commuting by foot to and from school with an appropriately adjusted and weighted backpack would have the dual benefit of providing valuable physical activity for school students and reducing road congestion. Intervention studies that aim to increase the number of school students walking or cycling to and from school could

significantly contribute to the improvement of quality of life for both students and adults.

Schoolbag carriage guidelines should also contain advice regarding other modes of transporting school students' belongings. In addition to possibly contributing to MSD, cycling while carrying a schoolbag may affect students' balance (Legg et al. 2003) and increase the risk of accidental injury. Trolley-bags are commonly used by urban travelers; however they have only recently been used to transport school belongings. Pulling ones belongings behind them on wheels removes the burden of load carriage. However, other challenges such as lifting it with one hand up stairs may predispose a user to MSD or acute injury. It appears that the usability of trolley-bags or their relationship with MSD or injury have not been studied in adults or children. Further research in this area would provide guidance for trolley-bag use.

## Conclusion

It is concluded that the effects of schoolbag design, adjustment carriage duration and weight on students' responses to carrying schoolbags were as follows:

- School students' preferred attributes in a backpack changed over short periods of experiential use (20 minutes) from 'style and image' to 'function and fit'. Also, backpacks preferred by students were associated with less muscular strain in the back and pressure in the shoulders.
- Load weight, hip-belt use and shoulder strap length had significant effects on shoulder strap tension forces and shoulder interface pressure during simulated schoolbag carriage.
- Posture, RPE, muscular strain and perceived ability to walk and balance were significantly affected when students' schoolbag load reached 10% BW, but were not affected by the duration of carriage over a school day for loads of up to 15% BW, or by shoulder strap tightness.

- The magnitude of self-reported muscular strain and MSD as a result of carrying 15% BW, suggests that carrying 15% BW may be excessive.
- Using a psychophysical approach, a maximum acceptable schoolbag weight of 10.4% (SD 3.8) BW was determined.

The objective evidence obtained in this thesis suggests that an upper schoolbag weight limit should be 10% of a school student's body weight. However, in addition to a recommended upper schoolbag weight, guidelines for schoolbag carriage should include recommendations on schoolbag design and adjustment. Schoolbag carriage guidelines may also address the duration of schoolbag carriage, although more research is required in this area. Based on postural, self-reported and psychophysical measures, the findings of this thesis support a recommended upper schoolbag weight of 10% BW.

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## ***Appendices***

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## Chapter 2 – *Schoolbag design*

### Appendix 1. Participant information and consent form

# ***Comparison of four different backpacks intended for school use***

## **PARENT / GUARDIAN and PARTICIPANT INFORMATION SHEET**

**Principal Researcher:** Hamish Mackie Ph 09 815-4321 x8012,  
email: [hmackie@unitec.ac.nz](mailto:hmackie@unitec.ac.nz)

**Research assistant:** Philippa Jones 021-149-3348

**Supervisor:** Assoc Prof Stephen Legg  
Ph 09 443-9700 x2786  
email: [S.J.Legg@massey.ac.nz](mailto:S.J.Legg@massey.ac.nz)

Thank you for permitting your child's participation in this study. We are conducting this research in order to determine school student's responses to different schoolbag designs. There is widespread concern regarding the load carriage demands placed on school students, however, there is very limited research in this area.

If you and your child agree to your child's participation in the study we would like them to attend the data collection session on the 9<sup>th</sup> of September.

When your child attends the data collection session, they will be asked to evaluate four backpacks each on three different occasions. On the first occasions they will be asked to evaluate each backpack as if they were examining them in a shop. On the second occasion they will be asked to wear the backpack and adjust it to the most comfortable fit using the instructions provided. On the last occasion, they will be asked to walk on a treadmill for 20-minutes at a self selected speed and backpack weight. Following each of these evaluations, your child will be asked to complete a short questionnaire.

All the data that we collect will be anonymous and only a code number will be used to identify your child's data. Only the principal researcher and research assistant will have a list of the names, contact details and code number of each participant. Once the data is collected it will be kept securely in a locked cabinet for at least 5 years. We will process the information to determine the outcomes of the research, however any published research will in no way identify your child as a participant in the study.

Please understand that your child has the following rights if they participate in this study:

- *to decline to participate*
- *to refuse to answer any particular questions;*
- *to withdraw from the study at any time (if they wish to withdraw from the study we will make arrangements for them to be picked up or delivered home at the nearest convenient time)*
- *to ask any questions about the study at any time during participation;*
- *to provide information on the understanding that their name will not be used unless you and your child give permission to the researcher;*
- *to be given access to a summary of the findings of the study when the study is concluded.*

Thank you for taking an interest in this study, we hope it will benefit all young people in the future.

If you have any queries regarding the research, please don't hesitate to contact myself or Dr Stephen Legg (supervisor). See contact details at the beginning of this sheet.

Regards,

Hamish Mackie (Principal Researcher)  
School of Sport  
UNITEC  
Private Bag 92025  
Mt Albert  
Auckland

## **Comparison of four different backpacks intended for school use**

### **CONSENT FORM**

*Please return this form to Hamish Mackie by Friday the 8<sup>th</sup> September*

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction and I understand that I may ask further questions at any time.

I understand I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to provide information to the researcher on the understanding that my name will not be used without my permission.

*(The information will be used only for this research and publications arising from this research project).*

I agree to participate in this study under the conditions set out in the Information Sheet.

**Signed:** .....

**Name:** .....

**Date:** .....

Parent or Guardian

**Signed:** .....

**Name:** .....

**Date:** .....

**Daytime contact telephone number in case of emergency:** .....

**Appendix 2.** Backpack comparison questionnaire

**Backpack Comparison Study**

**January 2001**

**Participant's Details**

Name: \_\_\_\_\_ Participant Number: \_\_\_\_\_

Gender: \_\_\_\_\_ Today's Date: \_\_\_\_\_

Age (yr.): \_\_\_\_\_ Weight (kg): \_\_\_\_\_

Height (cm): \_\_\_\_\_

**Initial pain or discomfort**

Do you currently have any musculoskeletal discomfort? (Circle one)

YES / NO

If yes, indicate where on the picture provided:

**Initial CRS Scores**

(Please use figure 1 to answer this page)

<b><u>Body Region</u></b>	<b><u>C R S Score</u></b>
<b>Back</b>	1.....
	2.....
	3.....

4.....  
5.....  
6.....  
7.....  
8.....  
9.....  
10.....  
11.....  
12.....  
**TOTAL**.....

**Initial CRS Scores**

(Please use figure 1 to answer this page)

**Front**

1.....  
2.....  
3.....  
4.....  
5.....  
6.....  
7.....  
8.....  
9.....  
10.....  
11.....  
12.....  
**TOTAL**.....

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**‘Shop-Test’ Questionnaire**

- What attributes are important to you when choosing a schoolbag?

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- Is colour and style a deciding factor? YES / NO
- On first impressions, which backpack would you most prefer to use as a schoolbag?

*Backpack A / Backpack B / Backpack C / Backpack D*

- Why? What stands out about this backpack?

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- After trying the backpacks on and checking out their features, which backpack do you prefer for use as a schoolbag?

*Backpack A / Backpack B / Backpack C / Backpack D*

- Why? What stands out about this backpack?

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- If you have changed your mind since first seeing the backpacks, what features of the new backpack made you alter your initial decision?

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- What **don't** you like about the backpacks you have not chosen?

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- How would you rate each of these bags for practicality? (E.g.: room for all your books and extras). *Please indicate your answer on the line with an X i.e.:*



**Very practical**

**Very impractical**

Backpack A



Backpack B



Backpack C



Backpack D



## Pain or discomfort prior to testing bag

Do you currently have any musculoskeletal discomfort? (Circle one)

YES / NO

If yes, indicate where on the picture provided:

### Initial CRS Scores

(Please use figure 1 to answer this page)

<b>Body Region</b>	<b>C R S Score</b>
<b>Back</b>	1.....
	2.....
	3.....

- 4.....
- 5.....
- 6.....
- 7.....
- 8.....
- 9.....
- 10.....
- 11.....
- 12.....

**TOTAL**.....

**Front**

- 1.....
- 2.....
- 3.....
- 4.....
- 5.....
- 6.....
- 7.....
- 8.....
- 9.....
- 10.....
- 11.....
- 12.....

**TOTAL**.....

---

## Pre-walk Questionnaire

**Backpack: A / B / C / D**

How easy / difficult is this backpack to adjust?



Whilst standing, how comfortable / uncomfortable do you feel with this backpack?



### Pain or discomfort in last 5 minutes of walk

(Please use figure 1 to answer this page)

	<u>Body Region</u>	<u>C R S Score</u>
<b>Back</b>	1.....	
	2.....	
	3.....	
	4.....	
	5.....	
	6.....	
	7.....	
	8.....	
	9.....	
	10.....	
	11.....	
	12.....	
		<b>TOTAL.....</b>
<b>Front</b>	1.....	
	2.....	
	3.....	
	4.....	
	5.....	
	6.....	
	7.....	



- Balance 
- Ease of Walking 

What did you like **most** about this backpack?

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Why **do** you like this feature(s)?

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What did you like **least** about this backpack?

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Why **don't** you like this feature(s)?

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## After using all Backpacks

Overall which backpack do you prefer? (Circle one)

**Backpack A / Backpack B / Backpack C / Backpack D**

Why do you prefer this backpack?

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**Thank you for your participation.**

## Chapter 3 – *Schoolbag carriage adjustment*

**Appendix 4.** Force and pressure measurement reliability data (refer to CD in back cover)

**Appendix 5.** Summarised data (refer to CD in back cover)

## Chapter 4 - *The temporal patterns of schoolbag carriage*

### Appendix 6. Information letter to students with consent form

## STUDENT INFORMATION LETTER

### Evaluation of school bag use

RESEARCHERS: Hamish Mackie and Philippa Jones

Dear Student,

We are conducting a study at UNITEC Institute of Technology, to determine the patterns of use of student's school bag and other belongings.

Your participation in the study will require that you meet with us at your school on two occasions. Each meeting will take approximately 10-15 minutes, either before school (8:00am) or after school (3:10pm), depending on what is most convenient for you and our research team. The first time we meet with you, we will measure your weight and height and collect video footage of you carrying your school bag and other belongings. We will then place a small device that measures physical activity into your school bag. We will then meet with you the following day to remove the device from your bag and ask you some questions about when you carried your school bag and other belongings.

All information you provide is confidential and your name will not be used in the study. You will have the absolute right of access to your data and the right to withdraw from the study at any stage.

If you have any queries or wish to know more, please do not hesitate to contact me on **815-4321 x8012**

If you agree to participate in the study, please **read and sign the consent form on the next page and bring it to our FIRST MEETING. Also don't forget to get your PARENT or GAURDIAN's signature.**

Thank you for your time.

Hamish Mackie  
Phone: (09) 815-4321 ext8012  
Email: hmackie@unitec.ac.nz

# STUDENT CONSENT FORM

## Evaluation of school bag use

RESEARCHERS: Hamish Mackie and Philippa Jones

I have been given and have understood, the explanation of this research project.

I have had an opportunity to ask questions and have them answered.

I understand that I may withdraw myself, or any information traceable to me, at any time without giving a reason.

I agree to take part in this research.

Signed: \_\_\_\_\_

Name: \_\_\_\_\_  
(Please print clearly)

Date: \_\_\_\_\_

Parent or gaurdian's signature:  
\_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

This study has been approved by the UNITEC Research Ethics Committee. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the Secretary Ph: 09 849-4180. Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.

*PLEASE BRING THIS FORM TO YOUR FIRST MEETING WITH US*

**Appendix 7. Participant interview sheet**

**School student load carriage interview sheet**

**Personal details**

Name: \_\_\_\_\_ Date:   Consent Form

Age: \_\_\_\_\_ years Male / Female   Time of interview

Height: \_\_\_\_\_ m Locker?  Time AM placed in bag

Weight: \_\_\_\_\_ kg Time AM removed from bag

Ethnicity: \_\_\_\_\_ Video Data collected

**Carried items**

	1	2	3	4	5	Comments
Item description (* carried today)						
Wt of item (kg)						
representativeness of wt						
Days per week carried						

**Temporal patterns**

<b>Getting to school</b>	Time left home _____	Time arrived at school _____
Items carried (%time)	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>
Mode of transport	<input type="text"/>	
<b>At school</b>		
<b>Event:</b>	<b>Time Period:</b> _____	
Items carried	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>
<b>Event:</b>	<b>Time Period:</b> _____	
Items carried	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>
<b>Event:</b>	<b>Time Period:</b> _____	
Items carried	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>
<b>Event:</b>	<b>Time Period:</b> _____	
Items carried	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>
<b>Event:</b>	<b>Time Period:</b> _____	
Items carried	<input type="text"/>	<input type="text"/>
Mode of carriage	<input type="text"/>	<input type="text"/>

<b>Event:</b>	<b>Time Period:</b>					
Items carried						
Mode of carriage						
<b>Event:</b>	<b>Time Period:</b>					
Items carried						
Mode of carriage						
<b>Event:</b>	<b>Time Period:</b>					
Items carried						
Mode of carriage						
<b>Event:</b>	<b>Time Period:</b>					
Items carried						
Mode of carriage						
<b>Event:</b>	<b>Time Period:</b>					
Items carried						
Mode of carriage						
<b>Getting home.</b> Time left fifth period						<b>Time arrived home</b>
Items carried (%time)						
Mode of carriage						
Mode of transport						

**Additional comments:**

**Appendix 8.** Activity monitor validation study:

## **Development of activity monitoring for determining load carriage patterns in school students.**

Mackie, H.W., Legg, S.J. and Beadle, J. (2004). Development of activity monitoring for determining load carriage patterns in school students. *Work: A Journal of Prevention, Assessment and Rehabilitation* 22, 231-237.

### **Abstract**

The loads that school students are carrying to, around and from school is an issue of increasing concern particularly as the long term effects of excessive load carriage on school student's musculoskeletal health is unknown. A greater understanding of the temporal patterns of student's load carriage, which usually involves backpacking, would assist in determining the magnitude of the problem that is faced by school students. The aim of this study was to determine the duration of school student's walking, running and stair climbing while backpacking and identify when student's take off and put on their backpacks using activity monitoring and video and therefore validate activity monitoring as a tool for measuring the temporal patterns of backpacking in school students. An activity monitor was secured in the backpacks of six school students while they completed a predefined physical activity course. Participants firstly completed the course following a set time pattern ('set course') and then repeated the course while performing activities as they pleased ('free course'). Video footage and activity monitor data were captured simultaneously. The activity monitor provided consistent visual differentiation between walking, running and taking off and putting on a backpack. The greatest variation between measures was for walking during the 'free course' (mean 8, SD 7 seconds), while the least variation between measures was for stair climbing during the 'set course' (mean 3, SD 2 seconds). There were no statistical differences between the activity monitor and video camera determined durations for any of the activities. These preliminary results suggest that automated activity monitoring may enable reliable analysis of

the temporal patterns of backpacking with little disruption to the user, although more work is required to verify this.

## **Introduction**

Public awareness of excessive load weights that are carried by some school students is growing. This awareness is partly as a result of studies that have highlighted the stress backpack weights impose on school students and speculated on the long-term effects on their musculoskeletal development [4, 5, 7, 8, 9, 11, 12, 13]. However, despite the recent studies of school student's load carriage, the current recommended guide for school student's maximum load carriage of 10% of body weight [7, 11, 12] has no scientific rationale and the limit does not consider other demands such as the duration, frequency or manner in which the load is carried.

The time spent backpacking, has been identified as being important when considering school student's load carriage. Negrini and Carabolona [8] found that fatigue during and time spent backpack carrying, but not the backpack's weight, were associated with back pain. Likewise, Grimmer et al. [4] found gender and age specific associations between school students' recent low back pain and the time spent carrying their backpacks. A greater understanding of the temporal patterns of backpacking would assist in determining the magnitude of the backpacking problem that is faced by school students.

Although the time spent backpacking has been identified as a component of school student's load carriage that requires consideration, no studies have systematically attempted to quantify school student's backpacking duration or the time spent performing common activities such as walking and running while wearing their backpacks. The reason for this might partially be because there has, in the past, been no obvious methodology that might conveniently allow the temporal measurement of school student's backpacking patterns.

A methodology designed to determine the temporal patterns of school student's backpack use must be non-invasive and should allow differentiation between types

of physical activity such as walking or running while backpacking, or putting on and taking off a backpack. The ability to distinguish between different activities is important as backpacking intensity and therefore the demands placed on the student differs between activities. The accurate measurement of the duration of each activity is also important as it relates directly to the total energy that the student must expend in order to carry their backpack.

The use of a daily diary has been used with school students; however, studies have reported inaccuracies in self-reporting physical activity [6, 2]. Video recording would be the most direct method of determining backpacking patterns among school students but would be considered too intrusive and therefore ethically unacceptable as the student's activity would need to be captured for an entire school day in order to determine their realistic backpacking patterns.

Alternatively, activity monitors, which typically use uni-axial accelerometers to measure acceleration changes that result from movement, might be capable of recording backpacking patterns in school students. Patterson et al. [10] concluded that activity monitors are capable of differentiating between different forms of physical activity in adults with a high correlation with other established forms of physical assessment. In addition Ekeland et al. [3] found that the Computer Science Applications (CSA) activity monitor provided a valid measure of activity intensity in coronary patients. No studies have used activity monitors to determine the physical activity patterns of school students while backpacking.

One of the limitations of activity monitors is that placement of the unit must be consistent to achieve reliable data output. Westerterp [14] reported that differing results are obtained from placing an activity monitor on the wrist, ankle and waist and that attaching an activity monitor closest to the centre of mass of the body appears to be the optimal.

It was proposed that an activity monitor placed within school student's backpacks could accurately and non-invasively determine the duration of distinguishable physical activities of school students such as walking, running and stair climbing

while wearing their backpacks and putting on and taking off their backpack. The only way to objectively assess the effectiveness of this methodology would be to simultaneously capture school student's backpacking patterns using video, so that the two methods could be directly compared.

Therefore, the aim of this study was to determine the duration of school student's walking, running and stair climbing while backpacking and identify when student's put on and take off their backpacks using activity monitoring and video simultaneously and therefore validate activity monitoring as a tool for measuring the temporal patterns of backpacking in school students.

## **Methods**

### **Study design**

The study was designed as a pilot validation study. Activity monitor and video data were measured simultaneously and compared within participants.

### **Equipment**

A device was needed that could directly or indirectly detect movement, sample at a frequency great enough to differentiate between movements, was lightweight and non-invasive, was relatively robust and capable of recording remotely for long periods of time.

A Computer Science and Applications Inc. [1] (CSA) activity monitor was chosen for this study. The CSA activity monitor is specifically designed for analysing human movement, particularly for measuring daily physical activity and the amount of movement that occurs during sleep. The device is contained within a small plastic matchbox sized case (5.0 x 4.1 x 1.5cm), weighs only 43gms and is robust and splash proof. The activity monitor has an adjustable measurement frequency and is capable of recording for up to 36 hours with at 1 Hz. The mechanism used to measure movement is a single channel uniaxial accelerometer that measures acceleration ranging in magnitude from 0.25 to 2.5 G-forces and samples at a

maximum of 10 Hz. Output frequencies can range from once every second to once every five minutes.

In order to determine whether or not the activity monitor would operate effectively when placed within a backpack, the activity monitor signal was evaluated after firstly attaching the activity monitor to a school student's hip followed by a short walk and secondly after placing it within the student's backpack followed by an identical walk.

When placed on the hip, the activity monitor was fixed to the participant's belt by a small pouch that was provided by the activity monitor's manufacturer. When placed within the backpack, it was secured within a foam rubber block that had a cut in one side, allowing the activity monitor to sit securely within the foam rubber. The foam block was then secured within the backpack. In both instances the student walked at a casual pace on level ground for one minute.

The only difference between placing the activity monitor on the body and placing it within the backpack was a small decrease in the amplitude of the data when the device was placed within the backpack. Based on this initial test, it was proposed that the activity monitor would be effective in detecting physical activity from within a backpack.

The manufacturer of the CSA Activity Monitor recommends that a one minute measurement frequency is generally accepted as sufficient for calculating energy expenditure while a 15 second measurement frequency is recommended for recording physical activity. Preliminary testing with the activity monitor determined that a one second measurement frequency produced the most appropriate output data by allowing different physical activities such as running and walking to be distinguished while allowing continuous data collection for at least 24 hours. The 10 Hz raw data mode would have allowed even better differentiation between physical activities, however, the storage capacity of the activity monitor would only allow approximately 3.5 hours of continuous data collection and therefore would not be sufficient in measuring activity over the period of a day, which would be the most

likely application in the future. The acceleration output from the activity monitor was not calibrated and therefore without units and for the purposes of this study called 'activity intensity'. The signal was not required to be calibrated as only the pattern and duration of the signal was of interest and not the actual values.

In order to validate the results obtained from the activity monitor, video was used as a 'gold standard' measure of each participant's physical activity. A hand-held digital Sony Handicam (25 Hz) was used to simultaneously capture each participant's physical activity as they completed prescribed tasks.

**Table 1.** Height, weight, backpack weight and backpack weight as a percentage of each participant's body weight.

<b>Participant</b>	<b>Height (m)</b>	<b>Weight (kg)</b>	<b>Bag Weight (kg)</b>	<b>Bag weight as % body weight</b>
<b>1</b>	1.44	37.0	2.9	7.8
<b>2</b>	1.59	61.0	3.7	6.1
<b>3</b>	1.44	37.0	1.8	4.9
<b>4</b>	1.60	47.5	3.6	7.6
<b>5</b>	1.55	48.7	3.2	6.6
<b>6</b>	1.59	48.2	3.4	7.1
<b>Mean (SD)</b>	1.54 (0.08)	46.6 (8.9)	3.1 (0.2)	6.7 (1.1)

## Participants

In previous studies [4, 11, 13] it was found that younger students carried a proportionately larger percentage of body weight and therefore must exert the most effort in terms of carrying their belongings to, around and from school. Therefore, six year 10 (all of 14 years of age, mean (SD) height 1.54(0.08) m and weight 46.6(8.9) kg) volunteers (3 male and 3 female) were recruited (Table 1) and parental

and participant consent was obtained prior to the start of the study. Participants were instructed to supply their own schoolbag weighted with a representation of their usual book-load and other school related belongings. The height and weight of each participant and backpack weight was recorded for each participant (Table 1).

## Procedure

Prior to data collection participants were instructed on the activities that were required of them. While putting on their activity monitor instrumented backpack, each participant completed a 'set course' of approximately 15-minutes while carrying their backpack as they normally would when attending school. The course incorporated in chronological order:

1. Walking at a steady pace for approximately five minutes on level concrete ground.
2. Walking up and down two flights of stairs
3. Taking backpack off, lowering to ground then putting it back on shoulders (3 times).
4. Running a short distance on level concrete ground (approximately 30 seconds)

Following the completion of this course, each participant was asked to repeat the course ('free course') while walking, running, stair climbing or taking off and putting their backpack on whenever they pleased. During each participant's completion of the 'set course' and the 'free course', the activity monitor recorded their physical activity while a researcher followed the participant with a video camera, capturing the physical activity of the participant simultaneously.

The purpose of the 'set course' was to maintain consistency between participants and demonstrate the activity monitor's ability to detect a set pattern of activity. The 'free course' was designed to replicate the less structured physical activity that school students are likely to encounter when backpacking in a daily environment and also remove the ability of the researcher to predict activity patterns, which might obscure the true capabilities of the activity monitor.

When data collection was completed, both the activity monitor data and video footage were analysed for each participant. The activity monitor data was always analysed first, before the researcher became familiar with the physical activity patterns shown by video footage. This ensured that the researcher relied on the activity monitor trace alone to determine the physical activity pattern of each participant. The mean and standard deviation (SD) duration of walking, running and stair climbing and the number of times the backpack was taken off and put back on was determined from both the activity monitor and the video footage. The mean absolute difference between the two methods was then calculated for each participant. The absolute difference was used as results for different individuals were either positive (the interpretation of the accelerometer trace was an overestimation of the physical activity duration determined by the video camera) or negative (the interpretation of the accelerometer trace was an underestimation of the physical activity duration determined by the video camera), giving the mean difference for the group a non-sensically low number. By using the absolute difference in durations, only the variation and not the sign was considered and a more realistic calculated mean difference between the two methods resulted.

The ANOVA method was then used to determine whether or not there were statistical differences between the activity monitor and video camera determined physical activity durations for walking, running and stair climbing.

## **Results**

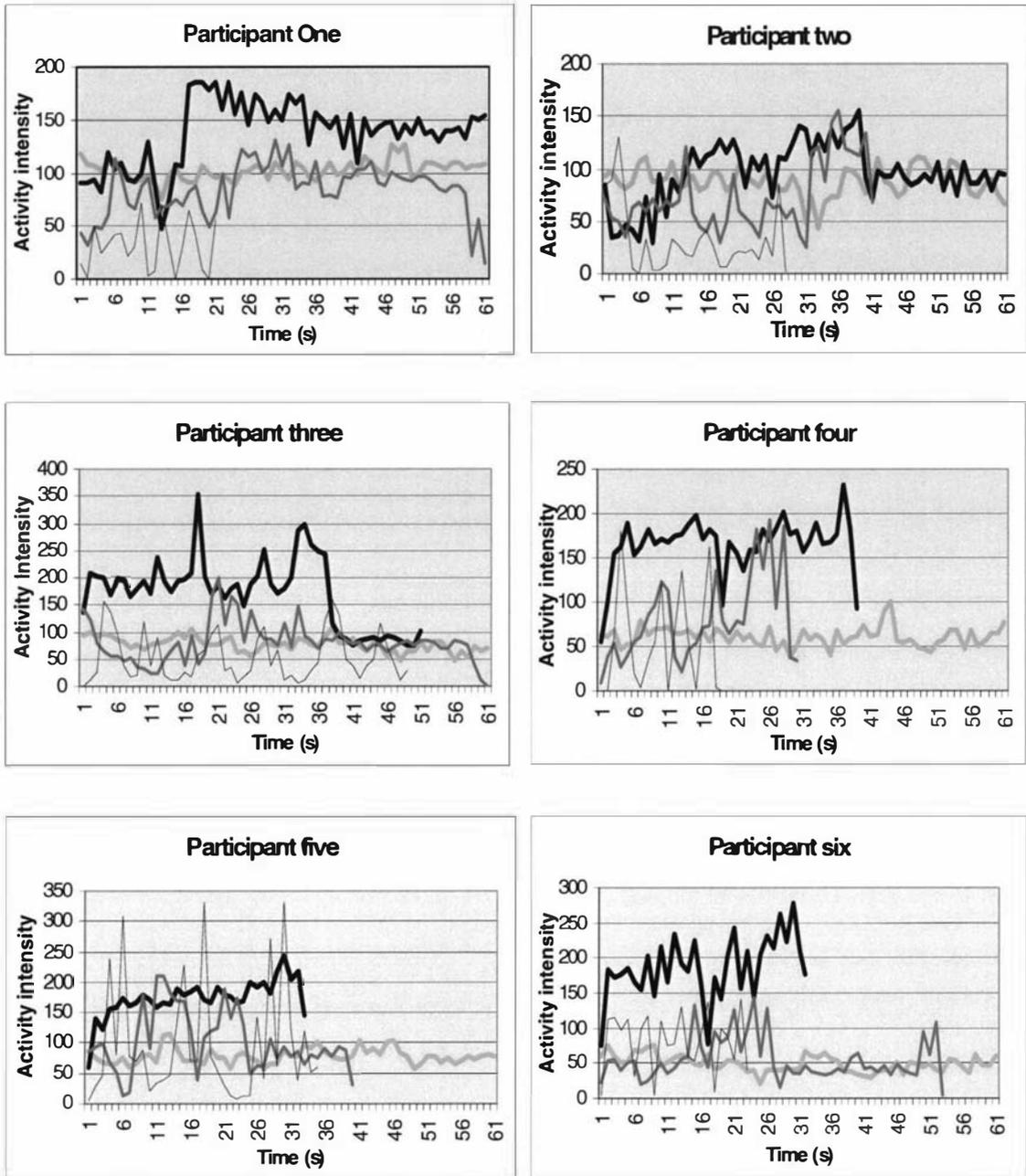
Upon visual inspection of the activity monitor traces from the six participants, changes in the amplitude of the activity intensity showed when each participant was involved in either walking, running or stair climbing. Figure 1 shows examples from each participant's trial depicting the different activities undertaken. In all figures, the amplitude of activity intensity is a clear indicator of the change between walking and running, with running producing a greater amplitude of activity intensity. The brief but relatively vigorous nature of movement experienced when participants lifted their backpacks is highlighted by the severe peaks in the activity trace and the steepness and magnitude of each peak corresponds to the speed or

vigour with which the participant took off and put on their backpack. Climbing and descending stairs was not as immediately discernible as walking, running and backpack donning and doffing and shows less of a pattern. However, the activity intensity pattern of stair climbing is more erratic in nature than that of steady walking and consistently results in a lower amplitude than movements associated with running. There were variations in activity monitor patterns between participants for the same activities although these differences were mainly shown in the amplitude of the activity intensity signal rather than the pattern shown between different activities.

Table 2 shows the mean and standard deviation (SD) time spent walking, running and stair climbing determined by activity monitor and video and mean absolute difference between the the durations determined by the two methods.

## **Set course**

For walking during the 'set course', the mean (SD) activity monitor determined duration was 291(26) seconds and the mean (SD) video camera determined duration was 294(30) seconds. The mean (SD) absolute difference was 7(4) seconds. For running during the 'set course', the mean (SD) activity monitor determined duration was 37(7) seconds and the mean (SD) video camera determined duration was 34(2) seconds. The mean (SD) absolute difference was 4(5) seconds. For stair climbing during the 'set course', the mean (SD) activity monitor determined duration was 31(4) seconds and the mean (SD) video camera determined duration was 31(2) seconds. The mean (SD) absolute difference was 3(2) seconds. During the 'set course' all participants took off and put on their backpacks three times in a row. This was detected by both the activity monitor and video camera methods. There were no statistical differences between the activity monitor and video camera determined durations for any of the activities.



**Key:**

- Running
- Walking
- Stair climbing
- Taking off and putting on backpack

**Figure 1.** Examples of activity intensity over time (seconds) for walking, running stair climbing and bag lifting for each participant during the ‘Set course’.

**Table 2.** Mean and standard deviation (SD) time (s) spent walking, running and stair climbing as detected by activity monitor and by video and mean absolute difference between methods (s). Note: None of the differences between the activity monitor and video results were statistically significant.

	Set course			Free course		
	Activity Monitor (s)	Video (s)	Mean Abs Diff (s)	Activity Monitor (s)	Video (s)	Mean Abs Diff (s)
<b>Walking</b>						
Mean (SD)	291 (26)	294 (30)	7 (4)	221 (53)	224 (47)	8 (7)
<b>Running</b>						
Mean (SD)	37 (7)	34 (2)	4 (5)	42 (15)	40 (17)	3 (3)
<b>Stair climbing</b>						
Mean (SD)	31 (4)	31 (2)	3 (2)	20 (11)	20 (2)	7 (6)

## Free course

For walking during the ‘free course’, the mean (SD) activity monitor determined duration was 221(53) seconds and the mean (SD) video camera determined duration was 224(47) seconds. The mean (SD) absolute difference was 8(7) seconds. For running during the ‘free course’, the mean (SD) activity monitor determined duration was 42(15) seconds and the mean (SD) video camera determined duration was 40(17) seconds. The mean (SD) absolute difference was 3(3) seconds. For stair climbing during the ‘free course’, the mean (SD) activity monitor determined duration was 20(11) seconds and the mean (SD) video camera determined duration was 20(2) seconds. The mean (SD) absolute difference was 7(6) seconds. During the ‘free course’ participants donned and doffed their backpacks between zero and three times. In all except one occasion there was agreement between the activity monitor and video regarding the number of times the backpack was taken off and put back on. For the exception, the activity monitor determined backpack ‘take off and put

on' count was two times while the video analysis determined backpack 'take off and put on' count was three times. There were no statistical differences between the activity monitor and video camera determined durations for any of the activities.

## Discussion

Based on the similarity of the activity monitor and video camera derived durations of walking, running and stair climbing, it could be argued that an activity monitor sampling at 1 Hz is an effective way to determine the temporal patterns of certain activities for school students carrying backpacks. This is supported by the clear visual differences between the activity traces for the different activities and the similarities of the durations between different activities.

These findings support the positive findings of Patterson et al. [10] and Ekeland et al. [3] in that it has been shown that an activity monitor may be a useful tool for monitoring physical activity. However, unlike previous studies, the findings of the present study suggests that the activity monitor can effectively measure the duration of different types of physical activity during backpacking.

The fact that there was little more difference between the activity monitor and video determined activity durations for the 'set course' than the 'free course', suggests that even when the researcher had no way of predicting when the different activities occurred, the activity monitor was still able to be used to distinguish between the start and end times of the different activities. Whether the effectiveness of the activity monitor would persist under even less controlled conditions such as the school play ground is unknown and requires further study.

There was variation in the activity monitor traces between individuals and this is probably due to individual differences in participant's gait and the weight and configuration of their backpacks. It was noticed that when the participants were walking more purposefully, the activity monitor trace resulted in being more consistent than when the participant was not as focused on the task at hand and distracted by events taking place around them (i.e. during the 'free course'). This

may have implications for use in schools where student's load carriage is less likely to be as closely supervised or structured. However, even if a student's gait was irregular, the activity monitor trace still clearly showed the duration and mode of student's physical activity.

An even more effective way to determine the temporal patterns of load carriage in school students might be to match activity monitor data with the student's daily timetable or a structured interview asking the student of their daily physical activity. The timetable or structured interview could be used to identify the broad pattern of student's activity and the activity monitor could be used to obtain a precise measure of the duration and frequency of physical activity and more accurately determine when the student is running, walking or taking off and putting on their backpack. Using this information, a profile could be developed that represents a 'typical' school day in terms of the duration and frequency of load carriage. This methodology may be considerably more accurate than those obtained solely from participant self-reporting. In addition, if the amount of load carried and the manner in which the load is carried could be determined from direct measures such as weighing and video capture, the physical demands of school student's load carriage may be completely defined. This type of comprehensive analysis of the physical demands of school student's load carriage should be carried out before objective guidelines on load carrying limits for school students are produced so that recommendations for school load carriage limits may be based on objective information rather than speculation.

Although the results of the present study are positive for walking, running, stair climbing and donning and doffing a backpack, other activities that may take place during load carriage such as standing or travelling in a vehicle while wearing a backpack have not been addressed. Although it may be rare that school students are ever perfectly still while carrying their backpacks, the reduced intensity or rhythm of movement due to these activities may be more difficult to detect using an activity monitor.

It was noticed that at the beginning and end of data collection when participants were standing awaiting instruction there was always a small and intermittent activity trace in response to the student's continual movement, even when standing. Also, the alternative to standing while wearing the backpack, which is doffing the backpack, was always distinguishable by a force spike as has been shown in the results of the present study. Nevertheless, further investigation must be carried out before this methodology can be used with confidence. In addition, the results are based on the responses of only six participants and are therefore preliminary in nature despite the relative consistency of the results across participants.

The results of the present study only apply to walking for short durations. Although it seems sensible that the methodology could be used to detect backpacking patterns for an entire school day, further study is required before the CSA activity monitor can be used confidently in more realistic applications.

## **Conclusion**

An activity monitor can be used to distinguish between and determine the duration of school students walking, running and stair climbing while backpacking and identify when student's take off and put on their backpack. The results do not address other less vigorous activities such as wearing a backpack while standing or travelling in a vehicle. Further work should be carried out to determine the extent to which activity monitors may be used to measure the temporal patterns of school student's load carriage in the field.

## References

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**Appendix 9. Summarised data (refer to CD in back cover)**

## Chapter 5 - *Schoolbag weight, shoulder strap adjustment and carriage duration*

**Appendix 10.** Parent / Participant information sheet and consent form (applies to chapters 5 and 6).

[Massey University letterhead]

### ***The physical demands of a simulated school day***

#### **PARENT / GUARDIAN and PARTICIPANT INFORMATION SHEET**

**Principal Researcher:** Hamish Mackie Ph 09 815-4321 x8012,  
email: hmackie@unitec.ac.nz

**Research assistant:** Philippa Jones 021-149-3348

**Supervisor:** Assoc Prof Stephen Legg, Ph 09 443-9700 x2786  
email: S.J.Legg@massey.ac.nz

Thank you for permitting your child's participation in this study. We are conducting this research in order to study the physical demands of a simulated school day. There is widespread concern regarding the load carriage demands placed on school students, however, there is very limited research in this area.

If you and your child agree to your child's participation in the study we would like them to attend the simulated school days from 8:15 am until approximately 5:00 pm for 6 days (not including Saturday and Sunday) and for a half day commencing at 8:15 for one day during the school holidays, beginning on the 23<sup>rd</sup> September. You will need to arrange for your child's transport to and from UNITEC each day.

All food and drink will be provided and if your child completes the 7-day programme, they will be allowed to keep the Billabong backpack that they will have used for the duration of the study.

When your child attends each simulated school day, they will be given a load which will include a school bag and possibly other items that are similar to the loads that school students often carry to school. They will then be instructed to participate in activities that are the same as they would normally experience at school, for example, sitting at a desk working, playing outside at lunch time or walking between classes. At 8:15am, 12:00 pm and 4:30 pm we will collect data from them. The data that we will collect will include a questionnaire and video. For the purposes of the

video data collection, it would help if your child wore a t-shirt or singlet and shorts, there are changing facilities here at UNITEC should they be required. Something warm to wear outside should be brought, in the event the weather is cold during outside activities.

As mentioned earlier, on the first day (Monday, 23<sup>rd</sup> Sept) your child will only be required for a half day. For this day we will measure your child's height and weight and we will undertake an exercise where the participants will be required to fill containers with sand to determine a weight that they feel they could carry for a school day. We will finish the day's activities by approximately 1:00pm.

On the first day of the programme please report to room 114-3008 (nearest gate 4 – see enclosed map). If you might have trouble finding this room, please contact myself or Philippa Jones for directions.

During each simulated school day your child will be supervised by Philippa Jones, myself and possibly one more assistant from the School of Sport at UNITEC.

All the data that we collect will be anonymous and only a code number will be used to identify your child's data. Only the principal researcher and research assistant will have a list of the names, contact details and code number of each participant. Once the data is collected it will be kept securely in a locked cabinet for at least 5 years. We will process the information to determine the outcomes of the research, however any published research will in no way identify your child as a participant in the study.

Please understand that your child has the following rights if they participate in this study:

- *to decline to participate*
- *to refuse to answer any particular questions;*
- *to withdraw from the study at any time (if they wish to withdraw from the study we will make arrangements for them to be picked up or delivered home at the nearest convenient time)*
- *to ask any questions about the study at any time during participation;*
- *to provide information on the understanding that their name will not be used unless you and your child give permission to the researcher;*
- *to be given access to a summary of the findings of the study when the study is concluded.*

**Because we are providing food for the durations of your child's visit to UNITEC, please let us know if your child has any food requirements well in advance to the commencement of the study.**

Thank you for taking an interest in this study, we hope it will benefit all young people in the future.

If you have any queries regarding the research, please don't hesitate to contact me or Dr Stephen Legg (supervisor). See contact details at the beginning of this sheet.

CHECKLIST for items to bring:

- Shorts and t-shirt or singlet
- Something warm for outside
- Consent form completed and returned to Hamish Mackie BEFORE the 19<sup>th</sup> of September?

This project has been reviewed and approved by the Massey University Human Ethics Committee, PN Protocol 01/124. If you have any queries about the conduct of this research, please contact Professor Sylvia V Rumball, Assistant to the Vice-Chancellor (Equity and Ethics), telephone 06 350 5249, email [S.V.Rumball@massey.ac.nz](mailto:S.V.Rumball@massey.ac.nz)

Regards,

Hamish Mackie (Principal Researcher)  
School of Sport  
UNITEC  
Private Bag 92025  
Mt Albert  
Auckland

# Participant and parent/guardian consent form

## *The physical demands of a Simulated school day*

### CONSENT FORM

*Please return this form to Hamish Mackie by Friday the 19<sup>th</sup> September*

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction and I understand that I may ask further questions at any time.

I understand I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to provide information to the researcher on the understanding that my name will not be used without my permission.  
*(The information will be used only for this research and publications arising from this research project).*

I agree/do not agree to being video taped (circle one)

I also understand that I have the right to ask for the video recorder to be turned off at any time during the interview.

I agree to participate in this study under the conditions set out in the Information Sheet.

**Signed:** .....

**Name:** .....

**Date:** .....

Parent or Guardian

**Signed:** .....

**Name:** .....

**Date:** .....

Daytime contact telephone number in case of emergency: .....

Appendix 11. Questionnaire

**Simulated school day questionnaire  
September 2002**

**Participant's Details**

Today's Date: \_\_\_\_\_ Day Number: \_\_\_\_\_

Participant Name: \_\_\_\_\_ Participant Number: \_\_\_\_\_

Age (yr/months): \_\_\_\_\_

Height (cm): \_\_\_\_\_

Weight (kg): \_\_\_\_\_ Carrying Condition : \_\_\_\_\_

---

**Prior to data collection – Data collection #1:**

**8:25am**

Do you currently have any musculoskeletal discomfort? (Circle one) YES / NO

If yes, indicate where on the picture provided:

**Initial CRS Scores**

(Please use figure 1 to answer this page)

	<b>Body Region</b>	<b>C R S Score</b>
<b>Back</b>	1.....	
	2.....	
	3.....	
	4.....	
	5.....	
	6.....	
	7.....	
	8.....	
	9.....	
	10.....	
	11.....	
	12.....	
	<b>TOTAL.....</b>	
<b>Front</b>	1.....	
	2.....	
	3.....	
	4.....	
	5.....	
	6.....	
	7.....	
	8.....	
	9.....	
	10.....	





7. Please rate your physical effort (RPE) of lifting, carrying and walking with this load (Please use figure 2 to answer this question).

**RPE**

Please indicate how you felt when carrying this load:

**Muscular strain in:**

	little strain				lots of strain
• Shoulders	1	2	3	4	5
• Neck	1	2	3	4	5
• Back	1	2	3	4	5
• Upper Legs	1	2	3	4	5
• Lower Legs	1	2	3	4	5

**Pressure on the:**

	Little pressure				lots of pressure
• Shoulders	1	2	3	4	5
• Back	1	2	3	4	5

**Balance and walking:**

	Easy				difficult
• Ease of Balance	1	2	3	4	5
• Ease of Walking	1	2	3	4	5

**Note:** These questions were administered each day at 8:25am, 12:00pm and 4:30pm each day.

**Appendix 12.** Questionnaire reliability (refer to CD in back cover)

**Appendix 13.** Posture measurement reliability (refer to CD in back cover)

**Appendix 14.** Questionnaire raw data (refer to CD in back cover)

**Appendix 15.** Posture summarised data (refer to CD in back cover)