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

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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

1. 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 and Hong, 2000; Grimmer et al., 2002; Grimmer and Williams, 2000; Hong et al., 2000; Mackie et al., 2003; Malhoutra and Sen Gupta, 1965; Pascoe et al., 1997; Sander, 1979; Voll and Klimt, 1977; Whittfield 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; Malhoutra and Sen

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Gupta, 1965), gait (Cheung and Hong, 2000; Pascoe et al., 1997; Wang et al., 2001) and posture (Chansirinukor et al., 2001; Grimmer et al., 2002; Grimmer and Williams, 2000; Malhoutra and 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 and Iampietro, 1962; Kinoshita, 1985; Knapik et al., 1996; Legg and Mahanty, 1985,1986) 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 and Reid (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 and Hong, 2000; Hong et al., 2000; Malhoutra and Sen Gupta, 1965; Pascoe et al., 1997; Voll and Klimt, 1977; Whittfield et al., 2001), and 10% of body weight (BW) is generally accepted as a recommended maximum load for school students (Sander, 1979; Voll and Klimt, 1977). Recently studies have shown that no significant changes in oxygen consumption or gait occur until school students are carrying 15–20% of BW (Cheung and 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 and 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. (2004) 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.

2. 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 (Fig. 1) consists of a programmable three degree of freedom pneumatically driven platform, which supports interchangeable rigid mannequins. 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.