International Journal of Industrial Ergonomics 39 (2009) 703–707

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Effects of backpack load placement on pulmonary capacities of normal schoolchildren during upright stance

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ARTICLE INFO

Article history:
Received 1 December 2007
Received in revised form
17 March 2009
Accepted 17 March 2009
Available online 5 April 2009

Keywords:
Pulmonary function
Backpack
Load carriage
Schoolchildren
Load placement

ABSTRACT

Backpack carriage affects posture, physiological costs and physical performance. Limited literature concerning the effects of backpack load placement on pulmonary capacities of schoolchildren has been reported. The objective was to assess the effects of backpack load placement on pulmonary capacities of normal schoolchildren. Forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), peak expiratory flow (PEF), and forced expiratory flow ($FEF_{25-75\%}$) were measured in 22 normal schoolchildren with a mean age of 12 years during free standing and when carrying a backpack of 15% bodyweight with its center of gravity positioned at T7, T12 and L3. The main effect of load was found to be significant for FVC and FEV_1. However, no significant effect of load placements on the pulmonary function of schoolchildren was found. Manipulation of load placements may not alleviate the restrictive effects exerted on the pulmonary function resulted from backpack load carriage.

Relevance to industry: Daily carriage of a school backpack on the musculoskeletal health of children and adolescents has become an area of concern. Restrictive effects on the pulmonary function due to backpack carriage were reported and it is useful to explore whether these effects could be alleviated by manipulating the backpack center of gravity level.

1. Introduction

The impact of backpack carriage on physical performance has been investigated to establish guidelines for safe load limits, and the effect of backpack carriage on pulmonary function has been one of the main areas of interest. Backpack load carriage loads the spine symmetrically while maintaining stability (Chansirinukor et al., 2001; Knapik et al., 1996). Forward trunk inclination, change of the body center of gravity (COG) and gait occur as an adaptation to increases in backpack load (Chow et al., 2005a,b, 2006a,b, 2007a,b; Goodgold et al., 2002; Hong and Cheung, 2003). Hong and Brueggemann (2000) examined changes of gait pattern, heart rate and blood pressure of schoolboys carrying different backpack loads at waist level while walking on a treadmill. Trunk forward lean angle was significantly increased with loads of 15 and 20% bodyweight (BW) as compared to no load and 10% BW (Hong and Cheung, 2003). Loads of 15 and 20% BW were also shown to result in prolonged blood pressure recovery time. Heart rate was unchanged in carrying different loads.

Carrying heavy loads close to the trunk affects pulmonary function since the backpack system opposes the expansion of the chest wall during inspiration (Hong and Cheung, 2003; Legg and Cruz, 2004; Pal et al., 2009). Lai and Jones (2001a) found that a backpack load heavier than 10% BW imposes a restriction on lung volumes from their study of normal primary schoolchildren with mean age of 9.6 years old. They demonstrated that both forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1) decreased significantly when a kyphotic posture was adopted and when the load was increased to 20 and 30% BW. Li et al. (2003) found that walking with a backpack of 15 and 20% BW was associated with more rapid breathing. However, walking with a backpack of 10% BW did not significantly change trunk posture or respiration parameters. Chow et al. (2005b) demonstrated a significant decrease in FVC and FEV_1 at backpack loads of less than 10% BW on schoolgirls with and without moderate adolescent idiopathic scoliosis (AIS) during free standing and while carrying a standardized backpack load of 5, 7.5, 10, 12.5 and 15% BW.

Legg and Cruz (2004) reported that single strap backpack with a wide strap that was worn across the chest and shoulders in a diagonal manner appeared to produce a greater restrictive effect on the thorax, whereas the double strap backpack with thinner straps attached over each shoulder resulted in a lesser degree of

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doi:10.1016/j.ergon.2009.03.002

restriction. Load carriage systems which covered the entire trunk, such as jackets or combination of front and back backpacks, lost most pulmonary function. This has also been demonstrated with chest strapping (Caro et al., 1960; Ghesquiere et al., 1979; Legg and Cruz, 2004) and is additional to that of the weight of the load alone (Bygrave et al., 2004; Legg and Cruz, 2004).

It has been suggested that the load COG should be placed close to the body promoting antero-posterior and lateral stability utilizing the large muscle groups of the body (Legg and Mahanty, 1985; Stuempfle et al., 2004). However, carrying heavy loads close to the trunk affects lung function since the backpack frame, harness system and mass all oppose the expansion of the chest wall during inspiration (Ghesquiere et al., 1979; Legg, 1988; Legg and Cruz, 2004; Legg and Mahanty, 1985). These studies suggested that the backpack placement relative to the body should be considered for optimizing the effects on body biomechanics and pulmonary functions. Additionally, oxygen consumption, minute ventilation and perceived exertion were significantly lower when the load was carried in a high position versus a low position (Bobet and Norman, 1984; Liu, 2007; Stuempfle et al., 2004). Thus, it is hypothesized that the effects of a backpack on pulmonary function could be optimized by varying the backpack COG location and the objective of this study was to assess the effects of backpack load placement on pulmonary capacities of normal schoolchildren.

2. Methods and materials

In total 22 children (15 males, seven females) with a mean age, height and weight of 12.0 ± 0.6 years, 151 ± 6 cm and 40.4 ± 6.9 kg respectively were recruited. Human ethical approval was obtained and all participants were given a written consent form to be approved by their parents before participating in the study. Study participants who had any known musculoskeletal disorders, prior history of respiratory problems or were unable to stand upright on two feet were excluded from the study.

Spirometric parameters of the participants were measured during free standing and when carrying a double strap shoulder suspension backpack over both shoulders weighing 15% of participant's BW with its center of gravity COG positioned at T7, T12, and L3. Prior to commencement of testing, measurement of unloaded condition was conducted such that each participant acted as his/her own control for comparison of pulmonary functions under different loaded conditions. The order of backpack load placement was randomized and there was a rest between tests.

Standardized double straps nylon backpacks (TA-542 Mountain Wolf, Canada) with dimensions 47 × 29 × 20 cm were used. Each backpack was filled with an internal frame (13 × 23 × 36 cm, net weight: 0.9 kg), which was specifically designed to be adjustable for positioning the COG of the load at T7, T12 and L3 and produce a load of 15% BW (Fig. 1). Participants were asked to adjust the length of the shoulder straps to achieve a comfortable fit.

Fig. 1. Testing backpack with an internal frame for adjusting the position of the center of gravity of the load.

A cardiopulmonary function machine (SensorMedics Vmax 220 series, Viasys Healthcare Inc., Conshohocken, PA) was utilized to measure respiratory parameters. A standard volume syringe (3 L) was used to calibrate the machine before data collection and every 3 or 4 h (Ip et al., 2000). Disposable bacterial/viral filter and nose clips were used. Respiratory parameters including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), FEV_1/FVC ratio, peak expiratory flow (PEF) and forced expiratory flow ($FEF_{25-75\%}$) were recorded under unloaded condition and different load placement conditions. During the experiment, the study participants breathed through a mouthpiece inserted into their mouths for each trial. They were instructed to maintain a normal erect stance throughout with their spaced apart at a comfortable distance (Chow et al., 2005b). After the methodology had been explained and demonstrated, including proper use of the mouthpiece, the study participants were instructed to take a few normal breaths, inspire completely, and then to exhale as hard and fast and for as long as possible until their lungs were completely empty. The experimenter provided verbal encouragement until the exhalation exceeded 6 s or a 3 s plateau was observed and the participants were instructed to inhale. All lung volumes were corrected by body temperature and saturated vapor pressure (Legg and Mahanty, 1985; Loeb et al., 2008). A minimum of three acceptable trials were performed by each participant such that the largest FVC and the second largest FVC were reproducible within 0.2 L of each other (Loeb et al., 2008). All spirometric measurements were made according to the American Thoracic Society (ATS) recommendations (Loeb et al., 2008) and the entire experiment took approximately 50 min.

The data from the trial with the greatest sum value of FVC and FEV_1 were used for analysis (Chow et al., 2005b; Loeb et al., 2008). The absolute values of FVC, FEV_1, FEV_1/FVC ratio, PEF, and $FEF_{25-75\%}$ were recorded as well as normalized by the predicted values derived from a reference group of the same ethnic and geographic background (Lam et al., 1982). Since no prediction equation of $FEF_{25-75\%}$ was provided by Lam et al. (1982), the results were also normalized by the predicted values based on Knudson normset (Knudson et al., 1976, 1983).

The results of the absolute and normalized values of spirometric parameters were compared using one-way repeated measures analysis of variance (ANOVA) (SPSS 15.0, SPSS Inc., Chicago, IL) to investigate the effects of loading conditions (i.e. unloaded condition and loaded conditions at T7, T12 and L3 positions). The level of statistical significance was set at 0.05 and Bonferroni criteria were adopted for post-hoc comparisons.