

## Effect of single and double strap backpacks on lung function

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Carrying heavy and moderate military loads in backpacks or as body armour compresses the chest, causing a change in lung function that is typical of a restrictive ventilatory impairment. It is not known if a lighter backpack load of only 6 kg, such as is typical of loads carried by students, will have a similar effect on lung function. There have been no studies examining whether backpacks of different strapping styles have an effect on lung function. Several designs of student backpack have recently been introduced to the market. One of the most popular is a single-strap backpack. This study examined Forced Vital Capacity (FVC), Forced Expiratory Volume in one second ( $FEV_1$ ),  $FEV_1 \cdot FVC^{-1}\%$  and Peak Expiratory Flow (PEF) in 13 participants (4 males, 9 females) wearing each of two 6 kg backpacks, one with two shoulder straps (a Double Strap Backpack (DSB)) and the other with a single strap (a Single Strap Backpack (SSB)) worn across the shoulder and chest. In comparison with the control of no pack (N), SSB significantly reduced FVC (by 3.94%,  $p = 0.006$ ) but there were no significant differences in  $FEV_1$ ,  $FEV_1 \cdot FVC^{-1}\%$  and PEF. The DSB also significantly reduced FVC (by 1.97%,  $p = 0.034$ ) but no significant differences were found in  $FEV_1$ ,  $FEV_1 \cdot FVC^{-1}\%$  and PEF measures. In comparison with DSB, the SSB was associated with a significantly lower FVC (by 2.05%,  $p = 0.049$ ) and  $FEV_1$  (by 1.88%,  $p = 0.029$ ) but there were no significant changes in  $FEV_1 \cdot FVC^{-1}\%$  and PEF. It is concluded that a backpack load of 6 kg could produce a mild restrictive type of ventilatory impairment in lung function. This effect was greater for a single cross-chest strap than for a more conventional double strap harness.

### 1. Introduction

Studies of load carriage have mostly concentrated on the metabolic and biomechanical changes associated with load weight, walking speed, gradient, terrain and other factors as well as medical hazards and performance limitations (see reviews by Haisman 1988 and Knapik *et al.* 1996). Soldiers often carry extremely heavy loads (McCaig and Gooderson 1986). Firefighters, mine rescue workers and other emergency personnel carry oxygen tanks for breathing apparatus in a

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backpack frame system (Louhevaara *et al.* 1985, Smolander *et al.* 1985). Agricultural and forestry workers also often carry fertilizer or insecticide liquids containers on a backpack frame. Leisure or expeditionary hikers carry light day-packs or heavy alpine-style backpacks during recreational trail or mountain walking (Legg *et al.* 1997). Students in primary, secondary and tertiary education commonly use backpacks to carry their books and sporting equipment on a daily basis (Negrini *et al.* 1999, Grimmer *et al.* 1999, Grimmer and Williams, 2000, Whittfield *et al.* 2001, 2003).

There is, however, very little information on how the design, mass and mode of carriage of a backpack will affect the pulmonary ventilation of the user. Since the backpack frame, harness system and mass carried all oppose the expansion of the chest wall during inspiration, several studies have examined these effects and demonstrated that carrying heavy loads close to the trunk can affect lung function (Ghesquiere *et al.* 1979, Legg and Mahanty 1985, Epstein *et al.* 1987, Legg 1988, Muza *et al.* 1989). The changes in lung function are characterized by a restrictive type of ventilatory defect (Cotes 1979) in which Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second ( $FEV_1$ ) are reduced without a corresponding decrement in the  $FEV_1.FVC^{-1}$  ratio. It is possible that the respiratory restriction of the chest wall associated with load carriage could affect pulmonary ventilation during rest and exercise, resulting in the sensation of dyspnea and in arterial hypoxaemia, both of which could limit exercise capacity.

Legg and Mahanty (1985) reported a reduction in FVC,  $FEV_1$  and Maximum Voluntary Ventilation that could be sustained for 15 s ( $MVV_{15}$ ) by about 12% when a load equivalent to 35% of body weight (approximately 25 kg) was carried on the trunk in the form of a weighted jacket. When the same weight was carried in the backpack, the corresponding decrements were 5, 6 and 8% respectively. Epstein *et al.* (1987) reported the same reduction in lung function indices with a 30 kg backpack load. Muza *et al.* (1989) also reported the same decrement pattern in lung function. This was related to the magnitude of the load, such that a 10 kg backpack reduced FVC and  $FEV_1$  by 3%. Legg (1988) found that wearing military body armour also caused a mild restrictive decrement in lung function but questioned whether the mechanism was solely related to the weight of the load on the chest or trunk. He found a small reduction of 2–3% in FVC, but a larger reduction of 10.4% in  $MVV_{15}$  associated with the lightest of three weights of body armour and suggested that tightness of fit may be important in determining these changes in lung function. Restrictive changes in lung function have been demonstrated with chest strapping (Ghesquiere *et al.* 1979, Caro *et al.* 1960) and the use of spinal immobilization devices (another form of chest strapping, Bauer and Kowalski 1988). Bygrave *et al.* (2003) showed that the effect of tightness of fit of backpack on lung function is additional to that of the weight of the load alone.

In the last few years, there has been concern about musculoskeletal discomfort and increasing low back pain amongst school students throughout the western world, but very little about university students. One of the contributory factors is the weight and mode of carriage of books, computers and associated paraphernalia. Lai and Jones (2001) have reported that a schoolbag load of heavier than 10% of a child's weight will have a restrictive effect on lung volumes but there have been no studies of the effects of different types of backpack strapping systems or harnesses.

A topic that has attracted somewhat less attention is the effect that the mode of load carriage that is used by students. This is surprising because there has been an

explosion in variety and types of commercial backpacks for use by students. To the authors knowledge, only three commercial schoolbags have been developed with advice based upon ergonomics principles. These are the British National Back Pain Association (NBPA) schoolbag and the Australian PhysioPak and ChiroPak. These latter new schoolbags have only been recently been introduced to the world market and have both been manufactured by a single supplier, with advice from the University of South Australia Physiotherapy Department and the Chiropractic Association respectively. All of these are of a conventional style (backpack with two shoulder straps and a waist belt). A common and very recent popular design of schoolbag is one that has a single strap across the shoulder and chest. Numerous student backpacks of similar design are also available.

It is not known whether lung function is similarly affected with wearing a smaller and lighter schoolbag, nor whether there is any difference in lung function associated with different style (or strapping) of load carriage. The present study was therefore designed to determine whether a schoolbag weighted to 6 kg affects lung function and to determine if there is any difference in lung function associated with a conventional double strap backpack and a popular single strap (cross-chest) backpack harness.

## 2. Methods

### 2.1. *Participants*

Thirteen university students (4 males, 9 females), voluntarily participated in the study. Their mean (SD) physical characteristics were: age 27.3 (9.3) years, stature 163.3 (8.5) cm and body weight (BW) 66.3 (13.3) kg. Their previous experience in backpack load carriage was mainly limited to leisure backpacking. None had any current respiratory problems, nor any prior history of respiratory illness. No formal medical screening was performed but a medical officer interviewed the participants prior to the study and assessed them as all being suitable to participate. Each volunteer was informed of the possible health hazards and risks of the study.

### 2.2. *Backpack*

A double strap backpack (DSB) and a single strap backpack (SSB) were used in the study. The DSB was a LiteAlp DayPack, Standard Size (MacPack Wilderness Equipment Company Ltd, New Zealand). Its strapping harness comprised two padded shoulder straps. The SSB was a Unistrap Body Bag NSP 770 (Rockfield Ltd, China). Its strapping harness comprised a single 5 cm wide strap worn across the shoulder and the chest, secured by Velcro. Each backpack was filled with books to obtain a total pack weight of 6 kg. Participants were instructed to adjust the backpack to achieve a 'comfort fit' and given half an hour for familiarization with each backpack before the lung function tests were conducted.

### 2.3. *Lung function*

Lung function measurements were made according to standard methods (Cotes 1979) using a Vitalograph Single Breath Spirometer to determine FVC and FEV<sub>1</sub>, and a Wright Peak Flow Meter to determine peak expiratory flow (PEF) during maximally forced expirations, with the participants in an erect relaxed standing position and wearing comfortable clothing. The participants were given initial instruction and familiarization as a group on the techniques required and were also reminded before each testing procedure. They then provided three maximally forced

expirations under each of the following three conditions: no backpack (N), wearing the SSB and wearing the DSB. Thirty seconds was allowed between each maximal expiration and a minute of rest between each condition. The order of presentation of the conditions was according to a balanced randomized design. The highest value among the three attempts in each condition was used to compute the mean data for all subjects. Lung volumes and flows were corrected to body temperature and pressure of saturated gas (BTPS). One subject failed to undertake the PEF measurements due to personal reasons.

#### 2.4. Data analysis

Analysis of variance (ANOVA) was used to identify significant differences between conditions for each of the lung function measurements. Statistically significant differences were accepted at a probability level of 0.05. Post-hoc comparisons were used to identify the location of differences.

### 3. Results

The mean (SD) results are given in Table 1. In comparison with the control condition of no pack (N), the single-strap backpack (SSB) significantly reduced FVC (by 3.94%,  $p = 0.006$ ) but there were no significant differences in FEV<sub>1</sub>, FEV<sub>1</sub>.FVC<sup>-1</sup>% and PEF. The double-strap backpack (DSB) also significantly reduced FVC (by 1.97%,  $p = 0.034$ ) but no significant differences were found in FEV<sub>1</sub>, FEV<sub>1</sub>.FVC<sup>-1</sup>% and PEF measures.

In comparison with the condition of wearing the DSB, the SSB was associated with a significantly lower FVC (by 2.05%,  $p = 0.049$ ) and FEV<sub>1</sub> (by 1.88%,  $p = 0.029$ ). There were no significant changes in FEV<sub>1</sub>.FVC<sup>-1</sup>% and PEF.

### 4. Discussion

This study demonstrates that a backpack load of 6 kg influences lung function. The pattern of change in lung function characteristic of a mild restrictive ventilatory

Table 1. Effect of a single strap backpack (SSB) and double strap backpack (DSB) on lung function.

	No pack (N)	Single strap backpack (SSB)	Double strap backpack (DSB)	#Percentage difference		
				SSB/N (%)	DSB/N (%)	SSB/DSB (%)
<b>FVC (l) (n = 13)</b>						
Mean	3.55	3.41	3.48	3.94*	1.97*	2.05*
SD	0.83	0.86	0.84	( $p = 0.006$ )	( $p = 0.034$ )	( $p = 0.049$ )
<b>FEV<sub>1</sub> (l) (n = 13)</b>						
Mean	3.26	3.19	3.25	2.15	0.31	1.88*
SD	0.85	0.84	0.80	( $p = 0.309$ )	( $p = 0.840$ )	( $p = 0.029$ )
<b>FEV<sub>1</sub>.FVC<sup>-1</sup>% (n = 13)</b>						
Mean	91.53	93.58	93.34	2.24	1.97	0.27
SD	5.21	4.78	4.12	( $p = 0.187$ )	( $p = 0.232$ )	( $p = 0.739$ )
<b>PEF (l.s<sup>-1</sup>) (n = 12)</b>						
Mean	5.27	5.26	5.30	0.11	0.52	0.63
SD	0.70	0.84	0.87	( $p = 0.918$ )	( $p = 0.710$ )	( $p = 0.461$ )

#Percentage differences calculated as: SSB/N =  $(1 - \text{SSB}/\text{N}) \times 100$ , DSB/N =  $(1 - \text{DSB}/\text{N}) \times 100$ , SSB/DSB =  $(1 - \text{SSB}/\text{DSB}) \times 100$ . \*Significance at  $p = 0.05$ .

impairment (reduced FVC and FEV<sub>1</sub> but not in FEV<sub>1</sub>.FVC<sup>-1</sup>%) was evident for both the SBP and the DBP, but although the fall in FVC was statistically significant, that in FEV<sub>1</sub> was not. This finding is similar to that caused by wearing lightweight body armour (weighing less than 10 kg) (Legg 1988) and is the first study to demonstrate an effect with such a light backpack load.

Lai and Jones (2001) reported that a schoolbag load heavier than 10% of a child's weight was associated with a restrictive effect on lung volumes. Other studies have recommended 10% BW as the upper limit for schoolbag weight (Voll and Klimt 1977, National Back Pain Association 1997). In the present study the mean backpack load was 9.4% BW (range 6.9–12.8) (with four of the 13 participants having a load greater than 10% BW). The findings therefore indicate that a similar but milder restrictive effect may be produced with a backpack load of less than 10% BW.

Caro *et al.* (1960), Ghesquiere *et al.* (1979) and Bauer and Kowalski (1988) have shown that chest strapping and spinal splinting produce a restrictive change in lung function in patients. The present study is, however, the first to demonstrate that the style of backpack strapping can also significantly affect lung function in a similar way, since there was clear and statistically significant evidence of greater chest restriction for SSB than for DSB. The single-strap backpack had a wide-strap that was worn across the chest and shoulders in a diagonal manner and appears to have produced a greater restrictive effect on the thorax, whereas the double-strap backpack had thinner straps attached over each shoulder, resulting in a lesser degree of restriction. An additional possible reason for this finding was that some of the participants found that the strap of the SSB was too short for them so that they had difficulty in securing it firmly. Under these circumstances, it is possible that the effects observed may be due, at least in part, to tightness of fit similar to that reported by Bygrave *et al.* (2003). In the Bygrave study, patterns of changes in the indices of lung function that reflect flow in small airways were also reduced and associated with tightness of fit of the backpack harness. This suggested that a tightly fitting backpack could be associated with changes in lung function at the alveolar level. Since the present study has shown that the style of backpack strapping is associated with mild restrictive pattern of change in lung function, this may also be due to the tightness of fit that the style of backpack strapping presents. Thus, further studies examining the effect of the tightness of fit of the single-strap backpack harness on lung function, seem warranted. The use of single strap (cross-chest) backpack harnesses in walking, running and other more dynamic activities may have further effects on lung function.

In summary, this study has demonstrated a very small effect of a 6 kg backpack load on lung function characterized by a mild restrictive type of decrement. A single strap (cross-chest) backpack harness produced a greater restrictive effect than a more conventional double strap backpack harness. It is concluded that a double strap backpack loaded to 6 kg is associated with less restrictive change in lung function than a similarly weighted single strap backpack harness.

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