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ORIGINAL ARTICLE

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Cardio-respiratory adjustments and cost of locomotion in school children during backpack walking (the Italian Backpack Study)

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Abstract The use of a school backpack is one of the possible causes of back pain in children. Oxygen consumption ($\dot{V}O_2$), pulmonary ventilation, and heart rate (f_c) were measured in 35 pre-pubertal subjects [17 girls and 18 boys, mean (SD) age 11.3 (0.6) years]. They took part in a four-step experiment: (1) standing for 5 min, (2) walking at 3 km·h^{-1} for 7 min, (3) walking at 3 km·h^{-1} for 7 min carrying a school backpack weighing 8 kg, and (4) walking at 7 km·h^{-1} for 5 min with no load. The occurrence of back pain in the last 2–3 years and during the last 15 days was assessed for the subjects by means of a questionnaire. Mean (SD) standing $\dot{V}O_2$ was 215 (45) ml·min^{-1} during walking at 3 km·h^{-1}, 503 (101) ml·min^{-1} during walking without a load, and increased to 541 (98) ml·min^{-1} during walking with a load ($P < 0.01$). Carrying a backpack increased f_c only minimally. The energy cost of walking at 3 km·h^{-1} without the backpack was 10.0 (2.0) ml O_2·m^{-1}, and with the backpack was 10.8 (1.9) ml O_2·m^{-1} ($P < 0.01$). The net energy cost of locomotion was 0.129 (0.032) ml·kg body mass^{-1}·m^{-1} for the unloaded condition and slightly lower, at 0.123 (0.025) ml·kg body mass^{-1}·m^{-1} during loaded walking ($P < 0.05$). Ventilation did not change significantly between unloaded and loaded conditions. When the data were assessed according to the occurrence of back pain, the $f_c/\dot{V}O_2$ slope was significantly lower in children without back pain, even though the net energy cost of locomotion was similar. Overall, these data suggest that the cardiovascular effortrequired for locomotion while carrying a backpack is minimal. However, fatigability and back pain are more likely to take place in less physical performing subjects. Thus, the occurrence of back pain in schoolchildren during locomotion while carrying a backpack may improve with an improvement in their level of fitness.

Keywords Cost of locomotion · Backpack · Back pain · External load · Walking

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Introduction

Back pain is a relatively common symptom among schoolchildren, and one of the most frequent concerns among their parents (Balaguè et al. 1999). In many children back pain is recurrent or chronic, even before pubertal age (Taimela et al. 1997). The occurrence of back pain in children in Italy and in other European Countries is probably underestimated (Balaguè et al. 1999). A recent Italian study including 680 children (age range 10–14 years) showed a back pain life prevalence (defined as the percentage of persons known to have had the disease for at least part of their lives) of 64%, and a point prevalence (defined as the percentage of persons with the disease at a specified time point in time) of 12% (Negrini et al. 1998).

The use of backpacks to carry heavy weights to school has recently been postulated as one of the possible causes of back pain in children (Carabalona et al. 1998). In a recent report it was suggested that the occurrence of back pain in pre-adolescent and adolescent subjects was attributable to the heavy backpacks that children must carry to school, whose total mass amounts to several kilograms (Negrini et al. 1999). Preliminary results from the evaluation of a total of 237 children (age range 10–12 years) showed that the mean backpack mass was 9.2 kg, ranging between 4.5 and 12.5 kg during weekly usage. The mean backpack mass accounted for 22% of mean body mass (BM), the maximum occasionally reaching percentages as high as 46% (Negrini et al. 1999). In addition, the weight was frequently not properly balanced on the back, and occasionally was carried on a single shoulder, thus forcing the child to maintain an abnormal posture while walking.

In 1996, the epidemiological evidence of a high incidence of back pain in children, together with concern over the possible negative effects of carrying heavy weights in a backpack, prompted a multidisciplinary study, the Italian Backpack Study (IBS), with the financial support of the Ministry of Health, and involving various units, such as Orthopedy and Traumatology, Bioengineering, Sports Medicine, and Otoneurology and Posture Study Laboratories. The main objective of the IBS was to analyze the relationship, if any, between back pain and the use of a school backpack, in order to draw recommendations for the primary prevention of back pain in the young population, and to recognize high-risk patients, inwhom walking with a heavy weight on the back should be avoided or discouraged.

An interesting side-issue of "backpack walking" in children is the effects of the external loads in terms of cardio-respiratory adjustments and the energy cost of locomotion, the latter defined as the ratio between oxygen consumption ($\dot{V}O_2$, ml $O_2 \cdot min^{-1} \cdot kg^{-1}$, overall above resting conditions) and speed ($m \cdot min^{-1}$). In this regard, most of the available data (Soule and Goldman 1969; Thorstensson 1986) are from adults or post-pubertal young men (e.g., trained male subjects and soldiers), or refer to particular typesof locomotion (e.g., standing, running, or slope walking). Little is known about ambulation at walking velocities in children carrying backpacks for short distances, and in particular, there are no data available about the relationship between the energycost of walking with a backpack and the onset of back pain.

To address this issue, a study was carried out on a representative subgroup of the Italian Backpack Study participants. The primary aim was to determine the cardiorespiratory response and the cost of locomotion with and without a backpack. The secondary aim was to assess the association between the energy cost of locomotion with a backpack and the occurrence of back pain and fatigue. Finally, any causal relationship between energy expenditure,with and without a backpack, and some of the anthropometric characteristics of individual subjects (such as the presence of spine paramorphism) was also evaluated.

Methods

Subjects

Thirty-six pre-pubertal subjects (18 girls, 18 boys) participated in the study. These subjects were randomly selected from the participants of the IBS. Informed consent was obtained from the parents of each subject. The mean (SD) age, BM and height of the subjects ($n=36$) was 11.3 (0.6) years, 45.2 (9.6) kg and 151 (8) cm, respectively.

Before the beginning of the experimental procedures, all subjects underwent a medical and physical examination. Particular attention was paid to spinal column analysis. A standard 12-lead electrocardiographicrecording (Delta 1 Plus, Cardioline, Italy) and a spirometric control of the pulmonary function (Pony Spirometer, Cosmed, Italy) were performed. None of the children showed any sign of cardiorespiratory disease, except for one girl who had a clinical history of severe bronchial asthma. Seventeen subjects (47%) showed slight notes of column paramorphism, and two of them were affected by clinical scoliosis. Mean values of the anthropometric (including column evaluation) and functional parameters of the tested subjects, divided by gender, are given in Table 1. Due to a lipothymic episode during the treadmill test, one girl could not complete all evaluations, and her data was excluded from the analysis.

Backpacks

In the preliminary results of the IBS the mean backpack mass, calculated on a 6-day basis in our group of 36 subjects, was 8.5 (1.1) kg. Thus, a commercially available school backpack (Invicta, model Jolly, 35 cm high, 12.5 cm wide and 24.5 cm long) was filled with several weights, mimicking the books usually carried by schoolchildren, up to a total of 8 kg, including the backpack mass. The backpack was placed on both shoulders of the tested subject, fastened to the trunk, and fixed to the back in order to avoid lateral swinging during locomotion.

Experimental procedure and data collection

The test was carried out at a mean room temperature of 21–22°C, with a relative air humidity of 60–70%, and consisted of four consecutive steps: (1) standing at rest for 5 min, (2) walking at 3 $km \cdot h^{-1}$ for 7 min on a treadmill (Technogym, Run Race, Italy), (3) walking at 3 $km \cdot h^{-1}$ for 7 min carrying the backpack, and (4) walking at 7 $km \cdot h^{-1}$ for 5 min with no backpack load. The treadmill grade was set at 0%.

Respiratory gases were collected at rest for 5 min (step 1), and during the last 2 min (i.e., in steady-state conditions) of each of steps 2, 3 and 4. These gases were collected into a 150-l Douglas bag, which was connected to the subject via a silicon facial mask (Sensor Medics, Italy).

The following variables were measured: f_c ($beats \cdot min^{-1}$) by continuous electrocardiographic recording in the V_5-lead condition (Delta 1 Plus, Cardioline, Italy), pulmonary ventilation ($\dot{V}_E$, $l\,min^{-1}$)

Table 1 Characteristics of the subjects, divided by gender. Column paramorphisms include small lateral deviations of the spine, which are not usually greater than 15°, are modifiable and temporary, generally due to transient asymmetry of the spine, and mainly consequent to vicious postures or to slight differences in lower limb length. Values are expressed as the mean (SD). (*FEV_1* Forced expiratory volume)

Variable	Boys	Girls
n	18	17
Age (years)	11.4 (0.6)	11.2 (0.6)
Height (cm)	152 (8)	150 (7)
Mass (kg)	47 (9)	43 (10)
Vital capacity (l)	2.36 (0.39)	2.13 (0.31)
FEV_1 ($l \cdot s^{-1}$)	2.28 (0.33)	2.05 (0.27)*
Mean backpack mass (kg)	8.2 (1.2)	8.7 (0.8)
Backpack mass/body mass (%)	17.6 (3.0)	21.1 (4.3)*
Column paramorphism (%)	4 [22%]	11 [64%]
Scoliosis (%)	0 [0%]	2 [12%]

*$P < 0.05$ boys vs girls

by a dry gasometer (SIM Brunt, Italy), and O_2 and CO_2 concentrations (% vol) in expired air by a paramagnetic gas analyzer (Oxygen Analyser, Servomex, UK and Binos C, Fisher Rosemouth, Germany, respectively). Gas analyzers were calibrated before each experiment.

$\dot{V}O_2$ (l·min^{-1} and ml·kg^{-1}·min^{-1}) was determined by the standard open-circuit method. To estimate the maximal oxygen uptake ($\dot{V}O_{2max}$) for each subject, the $f_c/\dot{V}O_2$ relationship that was obtained during sub-maximal exercises at two different intensities (walking at 3 km·h^{-1} and 7 km·h^{-1}, without the backpack) was extrapolated to the maximal theoretical f_c (calculated as 220–age).

The metabolic cost of locomotion was calculated as the total cost (C_t, ml·m^{-1}; i.e., the total energy required to cover a distance of 1 m) and as the net cost (C, ml·kg^{-1}·m^{-1}; i.e., the energy required to cover a distance of 1 m per unit of transported mass, body + backpack), above resting condition.

Step frequency was measured by direct step counting at different treadmill velocities.

Questionnaires

A questionnaire was proposed to each subject, investigating the occurrence of back pain in the last 2–3 years and during the last 15 days, the duration of daily backpack carrying, and the subjective fatigability while walking with a backpack. According to Balaguè et al. (1999), children with a single occurrence of back pain were not considered positive for back pain. The practice of any sport activity, and the time spent in a sitting position (e.g., while studying, watching television or playing videogames) were also assessed.

Statistical analysis

The data are expressed as the mean (SD), unless otherwise indicated. For statistical comparisons, the unpaired Student's *t*-test or one-way analysis of variance were used, as appropriate. The χ^2 test was used to assess the independence between data clusters. To evaluate the $f_c/\dot{V}O_2$ relationship, a least square linear regression analysis, followed by a fit F-test to confirm linearity, was applied for each test to the four consecutive conditions of the experimental procedure (resting, 3 km·h^{-1}, 3 km·h^{-1} + backpack, 7 km·h^{-1}). The level of statistical significance was set at $P < 0.05$.

Results

Table 2 shows the mean values of the measured variables in boys and girls in resting conditions and during walking at 3 km·h^{-1} with and without a load, together with the extrapolated $\dot{V}O_{2max}$. All values are given as absolute and referred to 1 kg of BM or BM plus transported mass.

Resting $\dot{V}O_2$ and $\dot{V}O_{2max}$

Resting $\dot{V}O_2$ values were higher, although not significantly so, in boys than in girls. However, when referred to 1 kg of BM, resting $\dot{V}O_2$ values were similar between genders. Estimated $\dot{V}O_{2max}$ was 2192 (657) ml·min^{-1} in boys and 1742 (427) ml·min^{-1} in girls ($P < 0.001$). Again, the difference between genders was not statistically significant when $\dot{V}O_{2max}$ was referred to 1 kg of BM [47.2 (12.8) ml·min^{-1}·kg^{-1} in boys and 40.8 (7.9) ml·min^{-1}·kg^{-1} in girls].

Table 2 Metabolic and cardiorespiratory variables during walking without and with the backpack in boys and girls. The estimated maximal O_2 uptake ($\dot{V}O_{2max}$) is also given. Values are expressed as the mean (SD). (C_t Total energy required to cover a distance of 1 m, C energy required to cover a distance of 1 m per unit of transported mass (body + backpack) above resting condition, $\dot{V}_E$ minute ventilation)

Parameter	Boys	Girls	*P* value
Resting values			
$\dot{V}O_2$ (ml·min^{-1})	224 (43)	206 (47)	
$\dot{V}O_2$ (ml·min^{-1}·kg^{-1} body mass)	4.9 (1.2)	4.9 (1.0)	
$\dot{V}_E$ (l·min^{-1})	10.1 (4.0)	13.0 (3.4)	*
$\dot{V}_E$ (ml·min^{-1}·kg^{-1} body mass)	247 (115)	358 (150)	*
f_c (beats·min^{-1})	98 (10)	103 (16)	
3 km·h^{-1}			
$\dot{V}O_2$ (ml·min^{-1}) [%max]	523 (110) [23.8%]	482 (90) [27.6%]	
$\dot{V}O_2$ (ml·min^{-1}·kg^{-1} body mass)	11.3 (2.2)	11.4 (1.8)	
$\dot{V}_E$ (ml·min^{-1})	16.5 (4.8)	19.7 (7.1)	
$\dot{V}_E$ (ml·min^{-1}·kg^{-1} body mass)	398 (141)	525 (203)	*
f_c (beats·min^{-1})	110 (13)	114 (14)	
C_t (ml·m^{-1})	10.5 (2.2)	9.6 (1.8)	
C (ml·kg^{-1}·m^{-1})	0.128 (0.034)	0.131 (0.030)	
Step frequency (no. of steps·min^{-1})	60 (6)	58 (5)	
Step length (cm)	83.5 (7.5)	87.5 (7.8)	
3 km·h^{-1} with backpack			
$\dot{V}O_2$ (ml·min^{-1}) [%max]	563 (104) [25.6%]	518 (87) [29.7%]	
$\dot{V}O_2$ (ml·min^{-1}·kg^{-1} body mass)	10.3 (1.7)	10.3 (1.3)	
$\dot{V}_E$ (l·min^{-1})	17.2 (5.1)	18.4 (5.2)	
$\dot{V}_E$ (ml·min^{-1}·kg^{-1} body mass)	350 (115)	409 (129)	
f_c (beats·min^{-1})	114 (14)	118 (13)	
C_t (ml·m^{-1})	11.3 (2.0)	10.3 (1.7)	
C (ml·kg^{-1}·m^{-1})	0.124 (0.027)	0.122 (0.023)	
Step frequency (no. of steps·min^{-1})	57 (6)	54 (5)	
Step length (cm)	88.1 (8.5)	92.8 (8.4)	
Maximal values			
$\dot{V}O_2$ (ml·min^{-1})	2192 (657)	1742 (427)	*
$\dot{V}O_2$ (ml·min^{-1}·kg^{-1} body mass)	47.2 (12.8)	40.8 (7.9)	

*$P < 0.05$ boys vs girls

$\dot{V}O_2$ and the cost of locomotion during walking

During treadmill walking at 3 km·h^{-1}, $\dot{V}O_2$ almost doubled from resting values in both genders. When normalized for BM the energy consumption was similar in both genders [11.3 (2.2) ml·min^{-1}·kg^{-1} in boys vs 11.4 (1.8) ml·min^{-1}·kg^{-1} in girls].

Since differences between boys and girls were not statistically significant, the values of $\dot{V}O_2$, C_t and C were pooled and analyzed irrespective of gender. The mean (SD) overall $\dot{V}O_2$ in the standing conditions at rest was 215 (45) ml·min^{-1}. During treadmill walking at 3 km·h^{-1}, it increased to 503 (101) ml·min^{-1} without the load, and to 541 (98) ml·min^{-1} with the backpack. This 7% increase in $\dot{V}O_2$ was statistically significant ($P < 0.001$). The value of C_t during walking without the backpack was 10.0 (2.0) ml·m^{-1}, with an increase of 8% [10.8 (1.9) ml·m^{-1}] during backpack locomotion ($P < 0.001$).

When normalized per BM, the overall mean resting $\dot{V}O_2$ was 4.9 (1.1) ml·min^{-1}·kg^{-1}. During walking on the treadmill at 3 km·h^{-1} without a backpack $\dot{V}O_2$ was 11.3 (2.0) ml·kg^{-1}·min^{-1}. While walking with the backpack, $\dot{V}O_2$ per kg of transported mass (BM + backpack) decreased to 10.3 (1.5) ml·kg^{-1}·min^{-1} (–8.9%, $P < 0.01$).

The value of C was 0.129 (0.032) ml·kg BM^{-1}·m^{-1} for the unloaded condition and slightly, but significantly lower during loaded walking [0.123 (0.025) ml·kg BM + backpack^{-1}·m^{-1}, $P < 0.05$].

The $\dot{V}O_2$ during walking at 3 km·h^{-1} was 23.8% and 27.6% of $\dot{V}O_{2max}$ in boys and girls, respectively. The corresponding values measured during backpack walking were about 2% higher.

f_c and oxygen pulse

Since f_c and oxygen pulse values were similar in boys and girls (Table 2), the individual values from both genders were pooled. The overall mean f_c was 100 (13) beats·min^{-1} at rest, increasing to 112 (13) beats·min^{-1} during walking without a backpack, and to 116 (13) beats·min^{-1} during walking with a backpack ($P < 0.001$). O_2 pulse data showed similar values during loaded and unloaded walking.

Ventilation

In resting conditions, values of $\dot{V}_E$ were different between genders (Table 2), being 10.1 (4.0) l·min^{-1} and 13.0 (3.4) l·min^{-1} in boys and girls, respectively ($P < 0.001$). When referred to 1 kg of BM, the value measured in girls was 1.45 times that found in boys. During walking, $\dot{V}_E$ increased by 1.4- to 1.6-fold compared to resting conditions in both genders. During loaded walking, $\dot{V}_E$ either did not increase, or eventually showed a small but significant decrease per kg BM ($P < 0.05$).

At rest, the ventilatory equivalent for O_2 ($\dot{V}_E/\dot{V}O_2$) was 52.2 (23.6) l·l O_2^{-1} in boys and 72.0 (23.3) l·l O_2^{-1} in girls ($P < 0.05$). Thesevalues decreased significantly during loaded ambulation to 34.3 (11.9) l·l O_2^{-1} in boys and 39.7 (11.8) l·l O_2^{-1} in girls, and became similar in both genders.

Step frequency

Step frequency decreased significantly during loaded vs unloaded conditions, from 59 (5) steps·min^{-1} to 56 (6) steps·min^{-1} ($P < 0.01$). Accordingly, step length increased from 85.5 (7.6) cm to 90.4 (8.4) cm ($P < 0.01$). The % ratio between step length and stature also increased during locomotion with a backpack [60 (6)% vs 57 (5)%, $P < 0.01$, for loaded and unloaded conditions, respectively].

Questionnaire

According to the questionnaire data, the prevalence for back pain in the last 2–3 years in our subjects was 54%, whereas the prevalence in the last 15 days was 17%. Other results of the proposed questionnaire are shown in Fig. 1. Thirty-five percent of the subjects walked daily with the backpack for between 5 and 10 min; about 15% walked for between 10 and 15 min, and 33% walked for more than 15 min. More than 80% of the children reported the occurrence of fatigability during backpack locomotion. Similarly, about 50% of the subjects normally spend more than 3 h of their leisure time in a sitting position.

Relationship between clinical features, energy consumption and questionnaire data

Figure 2 shows direct comparisons (pooled data) between children reporting back pain more than once in the last 2–3 years versus the other subjects for $f_c/\dot{V}O_2$ ratio (Fig. 2B) and C during walking with a backpack (Fig. 2A). Subjects with back pain showed a higher $f_c/\dot{V}O_2$ ratio ($P < 0.05$), in spite of similar C values.

Children with spine paramorphism did not show either higher energy costs, or higher $\dot{V}O_2$ during loaded ambulation.

Discussion

The cardiorespiratory response, the cost of locomotion and the occurrence of fatigability and back pain in schoolchildren carrying a backpack were evaluated in this study, to determine whether the backpack load could be a factor contributing to back pain.

Energy consumption and backpack load

Children carrying heavy backpack loads to school are generally pre-pubertal, an age at which BM and physical

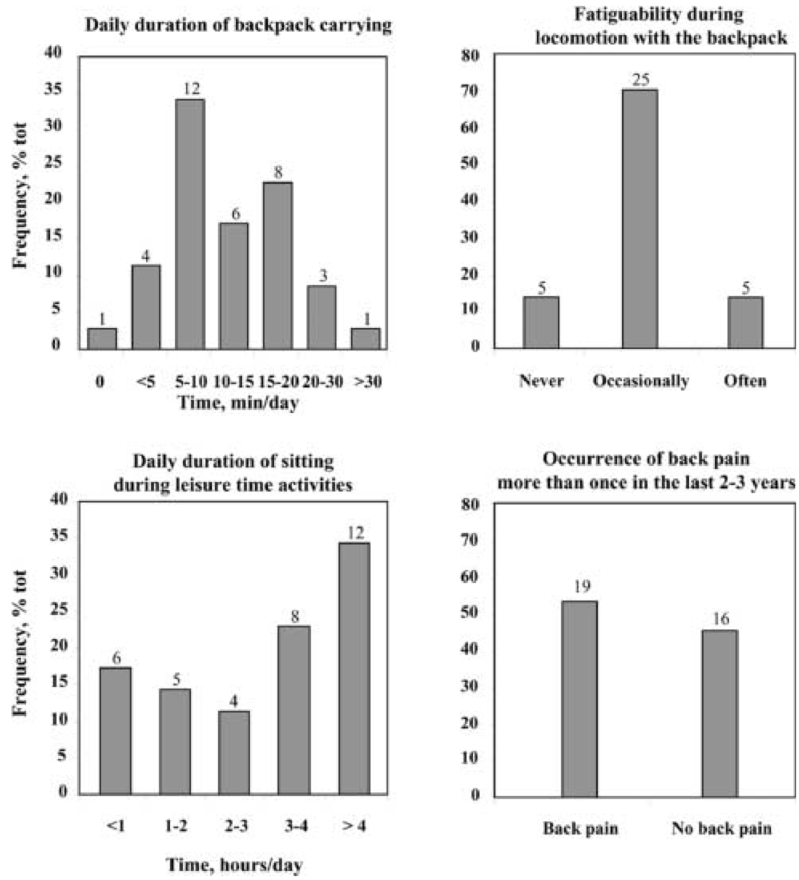

Fig. 1A–D Results of the questionnaire. Questions were about the daily duration of backpack carrying (**A**), sedentary activities (beyond school and dining **B**), the occurrence of fatigability (**C**) and the occurrence of back pain more than once in the last 2–3 years (**D**). Data were divided into bins, and are expressed as frequency (% total); values reported above the bin indicate the absolute number of subjects

stress tolerance can be highly variable. In addition, the paravertebral and upper body muscle mass may be only partially developed (Asmussen and Heeboll-Nielsen 1955). Therefore, the first question addressed by the present study was whether locomotion with a backpack in children requires a high physical effort, and consequently can only be well tolerated by those individuals with a higher degree of upper body muscular development.

The locomotion velocity used for laboratory assessments (3 $km{\cdot}h^{-1}$) was chosen to reproduce closely the walking conditions experienced by childrengoing to school. Although children are expected to walk at their "optimal" speed, they are used to maintaining a lower than "optimal" average speed, calculated during a preliminary assessment to be around 3 $km{\cdot}h^{-1}$. Thus, the speed we adopted was lower than the "optimal", expected to be about 4.5 $km{\cdot}h^{-1}$ for subjects who are 150 cm high, as were those in our study (Cavagna et al. 1983).

Usually, the backpack mass is highly variable between subjects and on different days of the week. Previous calculations estimated it to have a mean mass of 8.2 kg in boys and 8.7 kg in girls, occasionally reaching a maximum of 13 kg. The assessed average values accounted for 18% and 21% of BM in boys and girls, respectively.

A large body of literature (Asmussen and Heeboll-Nielsen 1956; Astrand 1960; Cavagna et al. 1983) has demonstrated that in pre-pubertal subjects many of the variables investigated in the present study are similar between boys and girls, particularly when referred to 1 kg BM. Indeed, with the exception of $\dot{V}_E$, this was also the case in our study. Therefore, data were also pooled and analyzed without distinction between genders.

Our data relating to $\dot{V}O_2$ are superimposable upon those obtained by other authors on children walking at 3 $km{\cdot}h^{-1}$. For example, Unnithan et al. (1999) reported a mean $\dot{V}O_2$ of 10.2 $ml{\cdot}min^{-1}{\cdot}kg^{-1}$ in 13-year-old children. A literature review by Fisher and Gullickson (1978) found similar results in the healthy adult population.

We observed that children walking at 3 $km{\cdot}h^{-1}$ carrying a backpack load corresponding to about 8% of BM produced an increase in $\dot{V}O_2$ of 35–40 $ml{\cdot}min^{-1}$, corresponding to a 7% increase compared to that produced during unloaded walking at the same speed (Table 2). Walking at 3 $km{\cdot}h^{-1}$ without backpack required a $\dot{V}O_2$ that was about 24% of $\dot{V}O_{2max}$ in boys, and 28% of $\dot{V}O_{2max}$ in girls. The carriage of a load increased these values to 26.4% in boys and 39.7% in girls, a practically negligible increase, even if boys and girls were carrying weights corresponding to 17.6% and 21.4% of their BM, respectively. If we consider that the anaerobic threshold at pre-pubertal age is about 55–65% of $\dot{V}O_{2max}$ and that a physical effort that accounts for 30–40% of $\dot{V}O_{2max}$ can be tolerated for a long time without experiencing fatigue, the $\%\dot{V}O_{2max}$ values of our

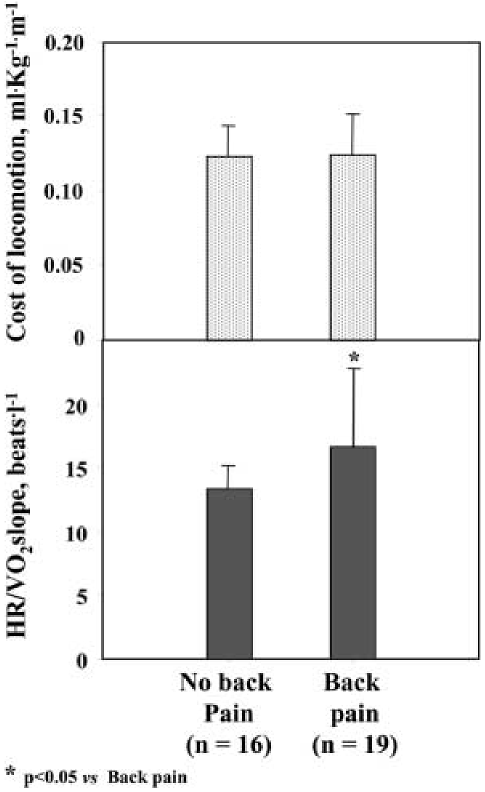

Fig. 2 Cost of locomotion (**A**) and heart rate (f_c)/oxygen consumption ($\dot{V}O_2$) slope (**B**) in two groups of subjects, divided according to whether or not they had experienced back pain more than once in the last 2–3 years. *$P < 0.05$ vs group without back pain

subjects during the backpack locomotion are very low. However, the occurrence of a localized fatigability of the spinal muscles cannot be ruled out and was indeed described as "fatigue" by the children.

Starting from a resting $\dot{V}O_2$ of 241 ml·min^{-1}, ambulation without a load required an increase in $\dot{V}O_2$ up to 503 ml·min^{-1}, and to a slightly higher value (541 ml·min^{-1}) in loaded conditions. Thus, even if the backpack mass accounted for a large percentage of BM, backpack locomotion does not seem to stress excessively the cardiorespiratory system. Furthermore, f_c increased only slightly (by about 4%) during loaded locomotion, compared to unloaded conditions. These results, together with the unchanged O_2 pulse between loaded and unloaded walking, suggest that the backpack load did not induce major changes in cardiovascular efficiency for similar levels of energy expenditure.

In addition, backpack locomotion did not require additional ventilation to sustain the increased $\dot{V}O_2$ compared to unloaded conditions (Table 2). Thus, carrying the backpack seemed to significantly improve the $\dot{V}_E/\dot{V}O_2$. This may suggest that the back load can to some extent limit pulmonary expansion during exercise, changing the ventilatory pattern to become less frequent and with a deeper tidal volume. However, this conclusion must be drawn with caution, since in our experiments the $\dot{V}_E/\dot{V}O_2$ was surprisingly high in resting conditions. Children tended to hyperventilate at the beginning of the experimental procedure, thus critically decreasing the respiratory efficiency. This trend occurred even during the 3 km·h^{-1} unloaded walking, and it gradually decreased during the execution of the test. Therefore further studies based on the actual measure of tidal volume and respiratory frequency in loaded and unloaded conditions are required to clarify this point.

Cost of locomotion with the backpack

The net cost of locomotion (C) during ambulation at 3 km·h^{-1} in our subjects is similar to that reported in previous studies on natural walking in children and teenagers: normative data by Waters et al. (1983a, b) reported a value of C per meter walked of 0.15 ml·kg^{-1}·m^{-1} in young people. The significant reduction in C during backpack walking reported in Table 2 is in agreement with previous data, showing a decreased energy cost in loaded conditions. Bourdin et al. (1995) demonstrated that the cost of locomotion is decreased in men walking on a treadmill and carrying a vertical load corresponding to 10% of their BM. Similar results were reported by Saibene (1990), who showed no changes in walking economy when carrying a load lower than 10% of BM. This may be due to a different distribution of BM, which tends to increase the level of the body's center of gravity during loaded walking. Such elevation of the center of gravity may enhance the elastic energy recovery at each step (Saibene 1990), and is particularly efficient in children. In addition, the lower step frequency and the higher step length observed during backpack locomotion yield an increase in the economy of walking (Silverman and Anderson 1972). Indeed, apart from the possible better recruitment of elastic energy, the elevation of the center of gravity in the loaded condition presumably leads to a smaller vertical displacement of the center of mass, which can produce a lower $\dot{V}O_2$ (Cavagna 1977). Concerning the effect of muscular activation on $\dot{V}O_2$, previous studies surprisingly showed a decreased electromyographic activity in the erector spinalis muscles when an external load of 19.5 kg was applied during ambulation in adult men (Bobet and Norman 1984).

Fatigability, paramorphism, back pain and energy expenditure

In spite of the low cost of locomotion associated with backpack carrying, many of the schoolchildren in our study have either sometimes (70%) or often (14%) experienced abnormal fatigability while walking with the backpack to or from school (Fig. 1). Many reasons can account for the reported fatigability. Indeed, what is reported as "fatigability" in our questionnaires is presumably due to a local complaint of the paravertebral regions more than to cardio-respiratory fatigue.

However, some alternative hypotheses can be postulated to explain the reported fatigability. The first one is the lack of an adequate level of physical fitness in these subjects. Less than half (45%, data not shown) of the tested subjects reported that they regularly practice sport. As shown in the questionnaire results (Fig. 1), children spend either 3–4 h (23%) or >4 h (34%) daily in the sitting position. These data are in agreement withthose from a 1997 study carried out on 2,200 third- and fourth-grade children, for whom the most common leisure-time activity was playing video games (33%) for the boys and doing homework (39%) for the girls. Overall, the children reported sedentary activities with an average metabolic equivalent of 4.2 MET (where the MET is a unit representing multiples of the resting metabolic rate; 1 MET = 3.5 ml O_2·kg BM^{-1}·min^{-1}) for girls and 4.8 MET for boys (Harrel et al. 1997).

The second hypothesis may come from the variability in nutritional habits among schoolchildren, and especially in energy intake with breakfast. Nutritional assessment was beyond the gift of our study. However, this issue has been addressed extensively in a group of Italian schoolchildren of similar age, where two out of three of the tested population were found to eat more than 70 g of soluble sugar daily, 34% of which as snacks (Ferrante et al. 1995). Such an abnormal intake of rapidly absorbed sugars may account for the development of reactive hypoglycemia in the morning, and this can be a possible explanation for the reported fatigability of some children, even in accomplishing low energy-demanding tasks, such as carrying the backpack for short distances.

The third hypothesis lies in the experimental evidence that the cost of locomotion is increased critically when the external load is not symmetric, or if it is far away from the center of mass, as, for example, when it is carried by one hand or on a single shoulder (Marras and Davis 1998). The best position for carrying the load seems to be near the body's center of mass (i.e., near the lumbar section of the spine) as has been shown previously (Soule et al. 1978). It could be hypothesized that children reporting fatigability and eventually back pain might not distribute symmetrically the weights in their backpack. This aspect requires further direct observations, since in the present laboratory evaluation care was taken to distribute the weight symmetrically on both shoulders.

Notably, when subjects were divided into two subgroups according to whether or not they had reported experiencing back pain, the $f_c/\dot{V}O_2$ slope was significantly higher in the first subgroup (the back pain group; Fig. 2), even though the value of C was similar in both subgroups. This suggests that back pain is more likely to occur in less physical performing subjects.

Finally, in our study 42% of the tested subjects showed spinal column paramorphism (for details see Table 1). It can be argued that these paramorphisms can increase energy expenditure during loaded ambulation. However, when subjects were divided again into two subgroups, one with and the other without paramorphism, the former showed neither higher energy costs nor higher $\dot{V}O_2$ during loaded ambulation. This suggests that the presence of column paramorphism does not significantly affect energy expenditure during backpack locomotion.

Conclusions

The results of this study suggest that the cardiovascular effort required by backpack locomotion is minimal, although the transported load may account for a high percentage of the subject's BM. However, back pain is more likely to occur in less physical performing subjects, in whom fatigability can occur more frequently. Thus, an improvement in the physical fitness of schoolchildren appears to be one way of preventing the occurrence of back pain during locomotion with a school backpack in children.

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