Correlation Between Backpack Weight and Way of Carrying, Sagittal and Frontal Spinal Curvatures, Athletic Activity, and Dorsal and Low Back Pain in Schoolchildren and Adolescents

Article *in* Journal of Spinal Disorders & Techniques · February 2004

DOI: 10.1097/00024720-200402000-00008 · Source: PubMed

Correlation Between Backpack Weight and Way of Carrying, Sagittal and Frontal Spinal Curvatures, Athletic Activity, and Dorsal and Low Back Pain in Schoolchildren and Adolescents

Panagiotis Korovessis, MD, PhD, Georgios Koureas, MD, and Zisis Papazisis, MD

Abstract: This cross-sectional study was carried out to investigate any correlation between backpack carrying, spinal curvatures, and athletic activities on schoolchildren's dorsal (DP) and low back pain (LBP). Three thousand four hundred forty-one students aged from 9 to 15 years who carried backpacks to school were included in this study and asked for DP and LBP experiences in the school period while carrying the backpack. Nonradiating methods (surface back contour analysis) were used to indirectly measure frontal spinal curve (scoliosis) with the scoliometer and lateral curves (thoracic kyphosis and lumbar lordosis) with the kyphometer. All data analyses were undertaken regarding school year level, age, gender, sports participation, backpack weight, and way of carrying (one versus both shoulder) in relation to magnitude of scoliosis, thoracic kyphosis, lumbar lordosis, and DP and LBP while carrying the backpack. DP increased with increasing backpack weight ($P < 0.05$). The way (one versus both shoulder) of backpack carrying did not correlate either with DP or with LBP. Girls experienced much more LBP and DP than boys ($P < 0.001$). There was no difference in the prevalence of LBP and DP between adolescents and children. Students' age, height, and body weight as well as magnitude of kyphosis, lordosis, and scoliosis did not correlate with either LBP or DP. At the age of 11 years, girls and boys showed the highest prevalence for DP (72% and 38.5%, respectively), while at the age of 14 years, girls reported significantly ($P < 0.05$) more DP than boys. Girls showed the highest prevalence of LBP (71%) at the age of 11 years, while for the boys, it was at the age of 15 years (21%). Girls showed at the age of 11 years significantly more LBP ($P < 0.05$) than boys. Sports exposure seemed to increase LBP in girls ($P < 0.001$). The results of this study suggest a differential DP and LBP prevalence in schoolchildren and adolescents carrying backpacks with regard to gender and age. The peak in pain prevalence was immediately before puberty as well as immediately after its onset. Girls who participated in sports activities seem to experience more often DP and LBP than boys. Short children who carry backpacks as heavy as do tall children at the same age are more prone to LBP.

Received for publication March 23, 2003; accepted April 21, 2003.
From the Spine Unit, Orthopaedic Department, General Hospital "Agios Andreas," Patras, Greece

Reprints: Dr. Panagiotis Korovessis, Spine Unit, Orthopaedic Department, General Hospital "Agios Andreas," 26224 Petras, Greece (e-mail: korovess@otenet.gr).

Key Words: children, low back pain, dorsal pain, school backpack, scoliometer, kyphometer

(*J Spinal Disord Tech* 2004;17:33–40)

Load carrying by children and adolescents during the school period is a common topic discussed by parents and physicians. There is a widely held belief that repeated carrying of heavy backpacks increases the stresses applied on the spinal structures (intervertebral disc, facets, ligaments, etc) in children and adolescents.[1–6] As these structures are undergoing rapid growth, they are believed to undergo structural damage if additional load (such as heavy backpack carrying) is placed on them. Investigations to establish appropriate adolescent backpack load-carrying limits have used primarily retrospective reports of spinal symptoms and outcomes. As there are potentially many influences on adolescent spinal symptoms, direct causative links between load carrying and spinal pain are difficult to establish.

A previous cross-sectional investigation[7] that examined the effects of backpack weight on adolescents' head-on-neck posture showed that there was a significant increase of craniovertebral angle with increasing backpack load and age, more in girls than in boys.

The current cross-sectional investigation attempted to correlate backpack carrying and anthropometric features (gender, body weight, height), scoliosis, thoracic kyphosis, lumbar lordosis, and dorsal pain (DP) and low back pain (LBP) in schoolchildren and adolescents.

MATERIAL AND METHODS

Subject Selection

The authors (one team) visited, between October 1998 and June 2001, 36 primary and high schools in the Prefecture of Achaia, Peloponessos, Greece, after approval of the local National Department of Education. The ethics committee of the authors' institution provided ethics approval for the study. Each participating school had at least four classes of about 30 students within each school stage. The participants were almost equally distributed in age and gender in each class. In each primary school, the classes that participated in the current study were the three last school year stages (school years 4–6). In each high school, the first three school year stages participated (school years 7–9). For the purposes of this study, students with age range 9–11 years were considered as children and 12–15 years as adolescents. The total sample consisted of 1816 (53%) girls and 1625 (47%) boys from all schools that participated in this study, with a chronologic age of 12 ± 1.5 years (range 9–15 years). The mean ± SD chronologic age per year level was 9.4 ± 0.3 years for school year 4, 10.5 ± 0.2 years for school year 5, and 11.4 ± 0.5 years for school year 6 for elementary school and 12.6 ± 0.4 years for school year 7, 13.7 ± 0.6 years for school year 8, and 14.9 ± 0.7 years for school year 9 for high school. Participating schools randomly selected 140 classes of students, and written parental permission was requested before student participation. A total of 4225 students from the Achaia Prefecture were asked to participate in this study. This report presents analyses undertaken on a sample of 3441 (81%) students who carried backpacks. Seventy-one (2%) students who used satchels or other school bags were excluded from this study. Teachers indicated that 713 (17%) students were lost from the study because parents and/or the child refused consent, consent forms were not returned by the day of testing, rendering students were unavailable for testing, or the student was absent from the school on the day of testing. The characteristics of the students who did not participate in this study for the reasons mentioned above were similar to those who participated in the study. In the schools that participated in this study, the number of students who did not carry backpacks was very small so that any comparison with the large sample of the students who carried backpacks would be statistically incorrect. From this study, there were excluded students who were unable to stand independently as well as students with known neurologic disease and operation in the spine and pelvis.

The backpack weight was the load with which the student arrived at school and usually included educational material, sporting equipment, and personal items. The mean weight point (theoretical center of backpack) is usually located at the level of thoracolumbar junction T10–L2. Contact area between posterior surface of backpack and posterior surface of the student's body was estimated to be a surface of about 21 × 35 cm (posterior surfaces of the lower ribs, paravertebral muscles, and posterior elements of T10–L2 vertebrae). Owing to gravity, the contents of the backpacks were usually located in the lower two-thirds of the backpack.

The students were asked by the authors to compare and distinguish pain intensity while carrying the school backpack with that—if any—in summer and other holidays (Christmas, Easter, etc). Although it would be scientifically more important to get information about pain characteristics both in school period and in holidays or to randomize the students in two groups (individuals who wore backpacks and subjects who did not), in the current study, this was not the case because of technical and organizing difficulties (parents and children were unwilling to answer questionnaire on holidays, etc). Pain localization by the student in the lumbar spine was determined as LBP and in the thoracic spine as DP. The students were asked by one of the authors for current back pain and localization either in the thoracic and/or in the lumbar back region while backpack carrying in the school. No quantification of pain was made in this study because, to the authors' knowledge, there are no specific pain quantification questionnaires for schoolchildren, and, according to the authors' experience, the validity and reliability of such questionnaires would be, in this age range, questionable.

The same team of investigators visited each school to take all measurements. Because of the long duration of the examination procedure, only one or maximally two classes in each school were measured on each day. Data were collected in the morning in all schools for two reasons: to minimize the effect of fatigue and diurnal variation on measurements and because there are only morning schools in this country and the children were unwilling to come again in the afternoon for examination. Before testing, a short history was taken by one of the authors, including anthropometric data, sports activity, and pain localization. School bags were described as backpacks if they had two shoulder straps and if the bag was carried on the back. Some students carried this backpack on both shoulders and others on one shoulder. Children and teachers reported that there was a variation in backpack weight between 1 and 3 kg from day to day. The backpack weight that the girls carried (4.7 ± 1.2 kg) differed clinically but not statistically from that of the boys (4.5 ± 1.2 kg) (unpaired *t* test, $P = 0.06$). There was no statistically significant difference in the backpack weight that boys and girls carried within any year level.

All schoolchildren and their parents had received a letter from the examiners a few days before the examination day with the request the child carry his/her backpack in the usual way (one or two straps) including the maximal backpack content for at least 2 hours before the examination, under the observation of their parents (one of the parents accompanied his/her child to the school). In the province in this country, the children walk for relatively long distances (one-half to 1 hour) to school carrying backpacks. In the school, the children who participated in this study continued to carry their backpacks under the observation of the teachers. The children were not permitted to take these backpacks off during a 2-hour period.

No roentgenograms of the spine were made in any child in this study to avoid unnecessary radiation exposure. The authors performed "back surface contour analysis" with the use of Debrunner's Kyphometer[3,11] (Protek AG, Bern, Switzerland) to indirectly measure both thoracic kyphosis and lumbar lordosis and the scoliometer (Orthopedic Systems, Hayward, CA, USA) to indirectly measure scoliosis (axial trunk rotation; ATR). The results of back contour analysis were compared with the anthropometric data and DP and LBP prevalence values. Measurement of frontal (scoliosis) and sagittal (kyphosis, lordosis) plane spinal curvatures with nonradiating methods (scoliometer, kyphometer) represent back surface contour analysis, and the obtained values do not represent the real roentgenographic curve values. However, both the scoliometer (64–93%) and the kyphometer (84–98%) have been shown to be highly reliable and repeatable methods.[8–10,12] The authors are aware that only a detailed radiographic analysis including biplane total and segmental vertebral analysis will appropriately describe kyphosis, lordosis, and scoliosis.

Anthropometric Measures

Student and backpack weights were measured using the same digital electronic Mettler weightier (Mettler Instruments AG, Switzerland). The scales on the weightier were accurate to 0.01 kg over the range of known weights (from <1 to 120 kg). For analysis purposes, backpack weight was expressed both in raw form (kg) and as percentage of student's body weight. Body mass index (BMI) was also included in this study and was derived from measurements of students' heights and weights (BMI = body weight divided by squared height). Two additional parameters were calculated for comparisons: percentage value of backpack weight in relation to student's body weight and percentage value of backpack weight to student's height. Standing height was measured with the student barefoot. All individuals and parents were asked for any systematic athletic activities (basket ball, football, tennis, etc) that they performed at least three times a week for at least 1.5 hours each time. Sixty-six percent of the girls and 87% of the boys reported systematic athletic activities. Thoracic kyphosis and lumbar lordosis were indirectly measured with the kyphometer on standing position immediately after removal of the backpack with the use of an adjustable T-shaped[9,10] device with the examined individual keeping his/her arms straight and his/her hands on the T device at the level of his/her pelvis[9] according to the method described and modified previously.[3,13] The magnitude of total thoracic kyphosis was measured by a well-known reliable method,[9,14] from a proximal point above the spinous processes of the second to third thoracic vertebra to a distal point above the spinous processes of T11 and T12 . Lumbar lordosis[12] was measured with the kyphometer proximally from the spinous processes of T11 and T12 and distally from the spinous process of S1. These points of measurement were located by palpation because palpation methods of identifying vertebral levels are remarkably (97%) accurate.[15] The degrees of thoracic kyphosis[14] and lumbar lordosis[12] that were directly read on the scale of the kyphometer were included in the calculations, because there were no roentgenograms of the spine. Although the kyphometer value for thoracic kyphosis can be converted to roentgenographic Cobb angle with high precision with the use of a mathematic formula,[9] this was not used in this study because there was no formula to convert the kyphometer value for lumbar lordosis to the "real" radiographic (Cobb) angle. The coefficient of variation for lumbar lordosis measurements with the kyphometer has been shown to be very low (7.4%).[12] Scoliosis (ATR) was measured on the back of standing students in forward inclination (Adam test) with the scoliometer. The obtained values were not converted to roentgenographic scoliosis Cobb degree using a formula[10] because for scoliometer ATR values of <7°, the false-positive values increase.[10]

Data Analysis

All analyses were undertaken in strata of chronologic age (years 9–15) and school year (4–9) because of theoretical year-specific load-carrying requirements. Gender differences in all measurements were also calculated because of known differences in child and adolescent anthropometry.[16,17] Preliminary analyses showed a very strong correlation between school year level and student age (correlation coefficient $R^2 = 1$), which supported year level as a proxy for stages of spinal development. Gender and general anthropometric parameters (age, body weight, height) were correlated with specific parameters (backpack weight, scoliosis, thoracic kyphosis, lumbar lordosis, and localization of pain). As all variables were continuous, the crude association between backpack weight and way of carrying and DP, LBP, and other anthropometric parameters was estimated with the use of simple linear regression analysis (SLRA). The Yates corrected χ^2 test was used to compare nonparametric data. Correlation coefficients (r) of >0.16 (level of significance, $P < 0.05$ for 3441 measurements) were considered as significant. The unpaired t test was also used to compare parametric data between different groups.

RESULTS

The results are summarized in Tables 1–3 and shown in Figures 1–3.

TABLE 1. Anthropometric and Other Data in 3441 Students

Parameters	Mean	±1 SD
Age (y)	12	1.5
Ht (cm)	158	72
Wt (kg)	48	13
Backpack wt (kg)	4.6	1.2
Thoracic kyphosis* (spinous processes T2–T3 to T11–T12) (°)	33	9
Lumbar lordosis* (spinous processes T11–T12 to S1) (°)	31	9
AXR† (°)	5.8	1.6

*Debrunner's kyphometer value.
†ATR with scoliometer of at least 5° in 230 (7%) students.

TABLE 2. Correlation Coefficient (*R*) Matrix Between Anthropometric Parameters and DP and LBP

Pain Localization	Anthropometric Parameters: Age	Gender	Ht	Wt	Backpack Wt	Thoracic Kyphosis*	Lumbar Lordosis*	Scoliosis†	BMI	Percent Value Backpack Wt	Percent Value Backpack Ht
LBP	0.035	(−0.21)§	(−0.023)	0.003	0.02	0.016	0.1	0.08	0.031	(−0.028)	0.0034
DP	0.009	(−0.21)§	(−0.033)	(−0.01)	0.16‡	(−0.035)	0.01	0.009	(−0.002)	0.089	0.15‡

BMI = (student's wt/body ht) × 100 (kg/m^2); Percent value backpack wt = (wt of backpack/student's wt) × 100; Percent value backpack ht = (wt of backpack/student's ht) × 100.
*Back surface contour measure (kyphometer value).
†Back surface contour measure (scoliometer value).
Levels of significance: ‡$P < 0.05$ §$P < 0.01$.

LBP and DP Prevalence

Six hundred seventy-one (21%) participants reported LBP and 692 (21.4%) DP during backpack carrying. Two hundred ninety-one (8.7%) students reported simultaneously LBP and DP while backpack carrying.

The incidence of LBP and DP in each school class in boys and girls is shown in Figures 1 and 2, respectively.

Correlation Between DP and LBP and BMI, Gender, and Age

No significant correlation was shown between LBP and BMI (SLRA, $R = 0.037$) or between DP and BMI (SLRA, $R = 0.0052$) (Table 2). Boys had higher (but not significantly) BMI than girls (unpaired *t* test, $P = 0.38$) in school year 4 (chronologic age 9.4 ± 0.3 years), immediately before the onset of puberty. Thereafter, in the age range from 10.5 ± 0.2 to 14.9 ± 0.7 years, both genders had similar BMI (Fig. 3).

LBP, DP, and Gender

Girls reported significantly more LBP than boys (Table 2; Fig. 1). Sixteen percent of the boys and 46.7% of the girls reported LBP during backpack carrying (Yates corrected χ^2, $P < 0.001$); additionally, 62.6% of the girls and 23.8% of the boys reported DP (unpaired *t* test, $P < 0.001$) (Fig. 2).

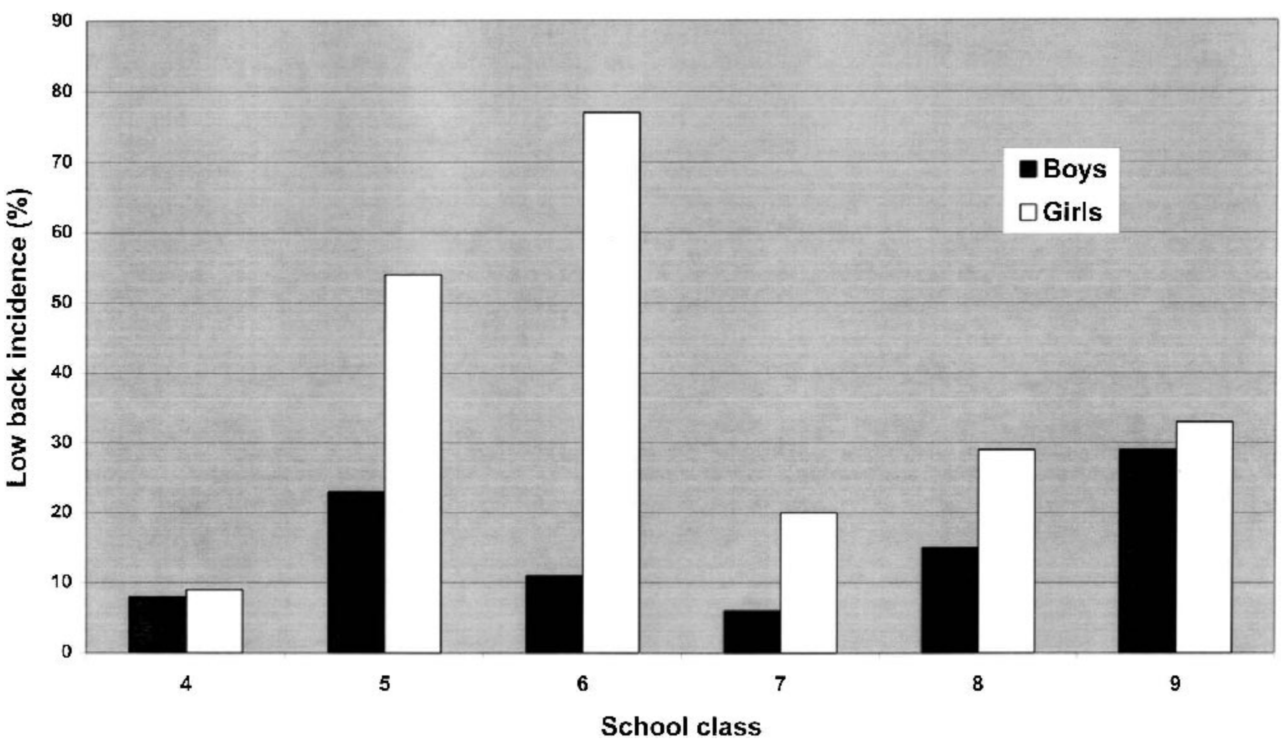

FIGURE 1. LBP incidence in girls versus boys plotted against school class.

TABLE 3. Scoliosis Curve Pattern and Magnitude in ATR (Back Surface Measures)

Pattern	%	Average ATR (°)
Right thoracic	3.29	5.7
Left thoracic	3.29	5.6
Thoracolumbar	0.3	6.2
Lumbar	0.3	5.3

ATR was measured by scoliometer.

Age, Height, and Sagittal Curvatures of Spine

Thoracic kyphosis and lumbar lordosis increase with increasing age (SLRA, $P < 0.001$) and student height (SLRA, $P < 0.01$). Age did not correlate with DP (unpaired *t* test, $P = 0.7$) or LBP (unpaired *t* test, $P = 0.5$).

The students' height did not correlate with DP (unpaired *t* test, $P = 0.89$) or LBP (unpaired *t* test, $P = 0.55$)

There was no correlation between thoracic kyphosis and lumbar lordosis and DP and LBP (correlation coefficients 0.01–0.1) (Table 2).

Way of Backpack Carrying (One Shoulder Versus Both Shoulders) and Pain

Three thousand sixty-one (91%) students carried their backpacks over both shoulders, while only 280 (9%) carried them over one shoulder. This way of carrying the backpack was the usual method that the students carried it to school. The hypothesis in this study that loaded backpacks carried over one shoulder may be possibly associated with much more LBP and/or DP than when carried over both shoulders was rejected for all students (Yates corrected χ^2, $P = 0.24$ and $P = 0.88$, respectively). There was no difference in way of backpack carrying (one versus both shoulders) between different ages (SLRA, $R = 0.057$) and genders (SLRA, $R = -0.08$).

Correlation Between Percentage Value Backpack Weight [(Backpack Weight/Student Weight) × 100] and Pain

No correlation was shown between LBP and DP and backpack weight percentage (Table 2) (SLRA, $R = -0.028$ and 0.087, respectively).

Correlation Between Percentage Value Backpack Height [(Backpack Weight/Student Height) × 100] and Pain

There was a significant correlation between percentage of backpack weight and DP (SLRA = 0.15, $P < 0.05$) (Table 2).

Athletic Activities and LBP

Two thousand four hundred sixty-two (74%) of the participants reported athletic activities. Although boys had more

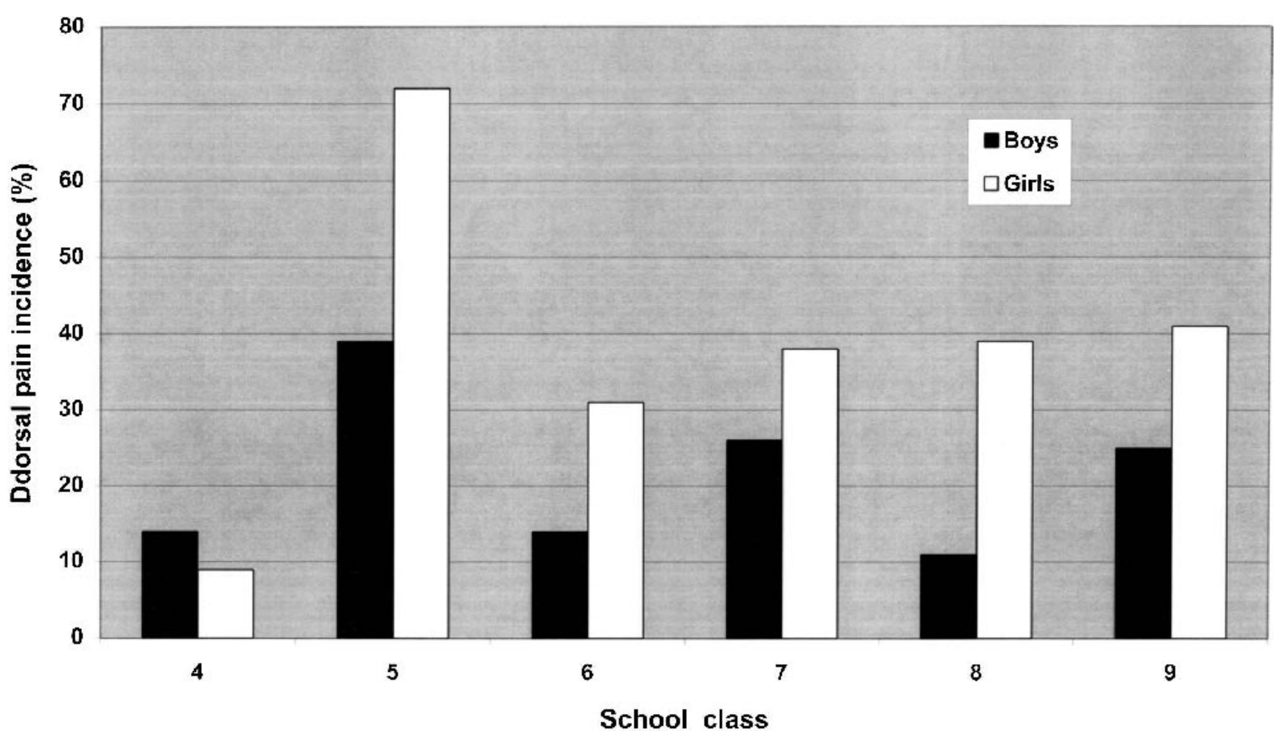

FIGURE 2. DP incidence in girls versus boys plotted against school class.

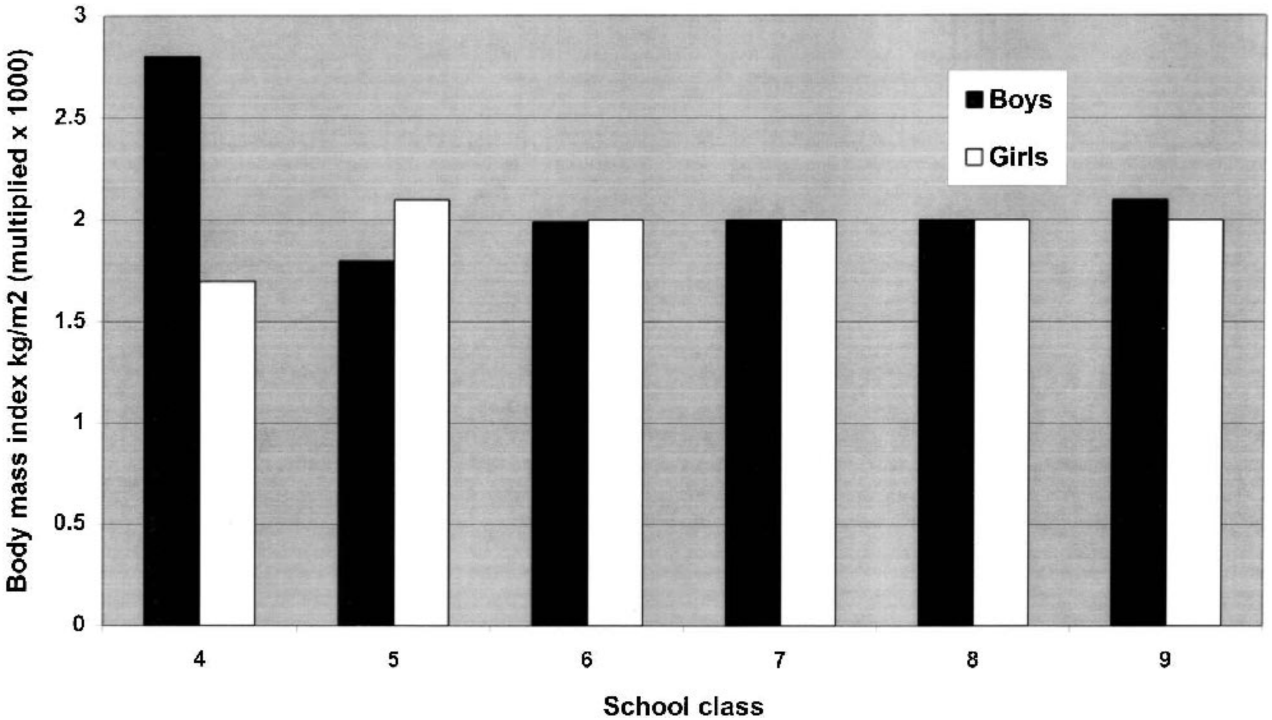

FIGURE 3. BMI in girls versus boys plotted against school class.

strenuous activities, sports exposure was significantly related to LBP only in girls (Yates corrected χ^2, $P < 0.001$).

Athletic Activities and DP

There was no difference in DP incidence between girls and boys with athletic activity (Yates corrected χ^2, $P = 0.98$).

DP and LBP Prevalence in Children Versus Adolescents

DP prevalence in children and adolescents was 33% and 26%, respectively (χ^2, $P = 0.9$). LBP prevalence in children and adolescents was 21.6% and 20.6%, respectively (Yates corrected χ^2, $P = 0.9$).

Scoliosis and DP and LBP

No correlation was shown between scoliosis and DP and LBP (Table 2).

DISCUSSION

This cross-sectional study was conducted to investigate the hypothesis of a possible correlation between backpack weight and way of carrying, frontal and sagittal spine curvatures, anthropometric data, sports activities, and DP and LBP prevalence in schoolchildren and adolescents with an age range from 9 to 15 years.

In Greece, there is an increasing belief among the parents of young school students that in the last decade, their children have had to carry heavier school backpacks than in the past. The current authors have not been able to find similar studies, and thus this study appears to be the first to have obtained data from such a large population-based sample, including young students in a rapidly growing age range (9–15 years).

LBP prevalence among schoolchildren varies from country to country and ranges from 20% to 51%.[15,17–25] This study showed that the overall prevalence of LBP in the schoolchildren in this country was 21% within the previously reported prevalence range. Previous studies[22,25,26] showed that LBP prevalence increases in the early teen years, earlier for girls than for boys. In the current series, LBP appears early at the age of 9 years with a prevalence range from 7.8% to 9%, with a peak prevalence at the age of 11 years for the boys and 12 years for the girls.

Wedderkopp et al[27] showed recently that DP is more common in childhood, whereas DP and LBP are equally common in childhood and adolescence. In the current study, there was no difference in DP and LBP prevalence between children and adolescents in the age range from 9 to 15 years.

In a similar previous study, Grimmer et al[7] showed significant gender differences in BMI for children in school years 9, 11, and 12, and all except the girls in school year 8 showed higher BMI than boys. In the current study, no gender-related differences in BMI were found in any school year, while BMI did not correlate with DP or LBP.

The authors showed that in the age range of 9–15 years, tall children carrying their backpack to the school do not experience much more DP or LBP than shorter children. This study also showed that a tall child who carries a backpack with the same load as shorter children reports significantly ($P < 0.05$) less DP, because the percentage value backpack height for a given load decreases with increasing height.

This study showed that children with increased thoracic kyphosis, lumbar lordosis, and scoliosis do not experience much more LBP and DP than their counterparts with decreased curves. However, there is a limitation that the values of both sagittal and frontal spinal curvatures that were measured with back surface methods do not represent roentgenographic values. However, the authors believe that if this study had a longitudinal design, there might be differences for pain in adolescents whose sagittal plane surface assessments were above and below 2 SD from the mean. This might be an interesting future project.

The detailed analysis of the results derived from this study showed that there was no gender-related difference in LBP prevalence in subjects in childhood. With the onset of puberty, there was a progressively increasing LBP prevalence until the age of 15 years. Others[2,6,13,15,17,18,20,21,24,26,28,29] have noted a similar incline in LBP prevalence. In contrast, this study showed that DP appears in puberty and thereafter its prevalence remains unchanged.

The possible adverse effect of athletic activities on LBP and DP has been previously analyzed, and some explanations (sports being injurious, muscle atrophy, disc degeneration, etc) have been given.[5,15,18–22,28,30,31] In this series, sports exposure seems to increase LBP prevalence in girls. There are some theoretical explanations for the observed increased LBP prevalence in girls in this series that, however, are derived from the recent literature.[7,15,20,32–34]

For the purposes of the current study, the authors have used a well-established instrument (kyphometer) to reliably measure thoracic kyphosis and lumbar lordosis, avoiding unethical exposure of young children to radiation. However, it is obvious that the magnitude of thoracic kyphosis and lumbar lordosis when measured with back surface contour methods does not represent the real radiologic curve value, cannot give segmental angle contributions to the curve, and does not tell the exact geometric configuration of the curve. However, the value that the kyphometer measures when it is applied at the endpoints of thoracic kyphosis[9] correlates significantly with the radiographic angle. Others have used the kyphometer also to directly measure lumbar lordosis.[12]

In this study, the authors have used the scoliometer that actually measures axial trunk rotation to indirectly measure scoliosis. The authors are aware that the scoliometer value does not represent the radiologic value of scoliosis, but it is in a close relationship with it.[10]

This study has several theoretical limitations: 1) Both the kyphometer and the scoliometer do not measure the actual radiologic degree of frontal and sagittal spinal curves; 2) radiography is the appropriate method for detecting differences in the shape and segmental contributions to curves in relation to pain that back surface contour methods cannot; 3) a longitudinal randomized study of DP and LBP based on a questionnaire given to students who wore backpack versus those who did not might be of more significance than a cross-sectional study, but it was not possible in the current study for the reasons mentioned previously; 4) the use of a questionnaire for quantification of intensity of LBP and DP should be of importance for a future study; and 5) there were no comparisons of DP and LBP reported during the holidays or summer versus those reported while wearing backpacks in the school period.

With the above-mentioned limitations in mind, the authors advise physicians to be aware that girls at the age of 11–12 years should carry light backpacks and avoid strenuous sports to decrease the probability of experiencing DP. Shorter children should not carry as heavy backpacks as tall children at the same age. Parents should not care about the way their child carries his/her backpack because (one or two straps) this is not of importance for back pain.

The authors believe that since this is the first multifactorial study to investigate the interaction between backpack wearing and other factors, additional longitudinal comparative studies should be performed based on these results to look at the variables here presented in more detail.

ACKNOWLEDGMENT

The authors thank Georgios Korovessis, Department for Computer Sciences, University of Ioannina, Ioannina, Greece, for his valuable contribution in the statistical analysis of the data of this paper.

REFERENCES

1. Bags linked to spinal deformities. *Australian Dr. Weekly.* October 6, 1989;4:42.
2. Datta S, Ramanathan N. Ergonomic comparison of seven ways of carrying loads on the horizontal plane. *Ergonomics*. 1971;14:269–278.
3. Deng YC, Goldsmith W. Response of a human head/neck/upper torso replica to dynamic loading: II. Analytic-numerical way. *J Biomech*. 1987;20:487–497.
4. Pope MH, Bevins T, Widler DG, et al. The relationship between anthropometric, postural, muscular and mobility characteristics of males aged 18–55. *Spine*. 1985;10:644–648.
5. Salminen JJ, Maki P, Oksanen A, et al. Spinal mobility and trunk muscle strength in 15-year-old schoolchildren with and without low back pain. *Spine*. 1992;17:405–411.
6. Troussier B, Davoine P, de Gaudemaris R, et al. Back pain in school children: a study among 1178 pupils. *Scand J Rehabil Med*. 1994;26:143–146.
7. Grimmer KA, Williams Gill KT. The associations between adolescent head-on-neck posture, backpack weight, and anthropometric features. *Spine*. 1999;24:2262–2267.
8. D'Osualdo F, Schierano S, Iannis M. Validation of clinical measurement of kyphosis with a simple instrument, the Acrometer. *Spine*. 1997;22:408–413.

9. Korovessis P, Papazisis Z, Petsinis G. Prediction of thoracic kyphosis with the use of the Debrunner's Kyphometer. *J Spinal Disord.* 2001;14: 67–72.
10. Korovessis PG, Stamatakis MV. Prediction of scoliotic Cobb angle with the use of the scoliometer. *Spine*. 1996;21:1661–1666.
11. Debrunner HU. Das Kyphometer. *Z. Orthop*. 1972;110:389–392.
12. Ohlen G, Spangfort E, Tangvall C. Measurement of spinal sagittal configuration and mobility with Debrunner's kyphometer. *Spine*. 1989;14: 580–583.
13. Stagnara P, de Mauroy JC, Dran G, et al. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for evaluation of kyphosis and lordosis. *Spine*. 1982;7:335–342.
14. Pheasant ST. Anthropometry and the design of workspaces. In: Wilson JR, Corlett EN, eds. *Evaluation of Human Work.* London: Taylor and Francis; 1995;69–75.
15. Salminen JJ. Erkintalo (Tertti) M, Laine M, et al. Low back pain in the young: a prospective three-year follow-up study of subjects with and without low back pain. *Spine*. 1995;20:2101–2107.
16. Helsing E, Reigo T, McWilliam J, et al. Cervical and lumbar lordosis and thoracic kyphosis in 8, 11 and 15-year-old children. *Eur J Orthop*. 1987; 9:129–138.
17. Mierau D, Cassidy JD, Yong-Hing K. Low back pain and straight leg raising in children and adolescents. *Spine*. 1989;14:526–528.
18. Balague F, Skovron ML, Nordin M, et al. Low back pain in schoolchildren: a study of familiar and psychological factors. *Spine*. 1995;20:1265–1270.
19. Deleted in proof.
20. Burton KA, Clarke RD, McClune TD, et al. The natural history of low back pain in adolescents. *Spine*. 1996;21:2323–2328.
21. Burton AK. Patterns of lumbar sagittal mobility: measurements by flexicurves. *Clin Biomech*. 1986;1:20–26.
22. Fairbank JCT, Pynsent PB, Van Poortvliet JA, et al. Influence of anthropometric factors and joint laxity in the incidence of adolescent low back pain. *Spine*. 1984;9:461–464.
23. Grantham VA. Backache in boys: a new problem? *Practitioner*. 1977; 218:226–229.
24. Olsen TL, Anderson RL, Dearwater ST, et al. The epidemiology of low back pain in an adolescent population. *Am J Public Health*. 1992;82:606–608.
25. Taimela S, Kujala UM, Vijanen T. The prevalence of low back pain among children and adolescents. *Spine*. 1997;22:1132–1136.
26. Leboeuf-Yde C, Kyvik OK. At what age does low back pain become a common problem? *Spine*. 1998;23:228–234.
27. Wedderkopp N. Leboeuf Y de, Andersen LB, et al. Back pain reporting in a Danish population-based sample of children and adolescents. *Spine*. 2001;26:1879–1883.
28. Salminen JJ, Eekintalo-Tertti MO, Paajanen HE. Magnetic resonance imaging findings of lumbar spine in the young: correlation with leisure time, physical activity, spinal mobility, and trunk muscle strength in 15-year-old pupils with or without low back pain. *J Spinal Disord*. 1993;6:386–391.
29. Turner PG, Green JH, Galasko CS. Back pain in childhood. *Spine*. 1989; 14:812–814.
30. Elliott BC, Davis JW, Khangure MS, et al. Disc degeneration and the young fast bowler in cricket. *Clin Biomech*. 1993;8:227–234.
31. Salminen JJ, Oksanen A, Maki P, et al. Leisure time physical activity in the jung: correlation with low-back pain, spinal mobility and trunk muscle strength in 15-year-old schoolchildren. *Int J Sports Med*. 1993;14:406–410.
32. Haley SM, Tada WL, Carmichael EM. Spinal mobility in young children: a normative study. *Phys Ther*. 1986;66:1697–1703.
33. Pirunsan U, Trott P, Grimmer K. Cervical posture in the sagittal plane: a comparison of three methods of measurement. Proceedings of Biennial Conference of the Manipulative Physiotherapy Association of Australia, Melbourne, November 1997, pp 145–150.
34. Sjolie AN, Ljunggren AE. The significance of high lumbar mobility and low lumbar strength for current and future low back pain in adolescents. *Spine*. 2001;26:2629–2646.

