ORIGINAL ARTICLE

Acta Orthop Traumatol Turc 2012;46(4):269-274
doi:10.3944/AOTT.2012.2678

Effects of unilateral backpack carriage on biomechanics of gait in adolescents: a kinematic analysis

Bahar ÖZGÜL[1], N. Ekin AKALAN[2], Shavkat KUCHIMOV[3], Fatma UYGUR[4], Yener TEMELLİ[5], M. Gülden POLAT[1]

[1]*Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Marmara University, İstanbul, Turkey;*
[2]*Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, İstanbul University, İstanbul, Turkey;*
[3]*Institute of Biomedical Engineering, Boğaziçi University, İstanbul, Turkey;*
[4]*Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Hacettepe University, Ankara, Turkey;*
[5]*Department of Orthopedics and Traumatology, Faculty of Medicine, İstanbul University, İstanbul, Turkey*

Objective: The aim of this study was to analyze the biomechanical alterations during unilateral backpack carriage in adolescents and to compare the kinematic parameters of the loaded and unloaded sides.

Methods: Twenty adolescents (mean age: 13±1.2 years) were assessed during walking with no backpack and with a backpack on one shoulder. The kinematic parameters of a gait at a self-selected speed were analyzed using motion analysis. Specific kinematic peak points were compared between asymmetric walking; unloaded, loaded side and mean of unloaded walking.

Results: Peak ankle dorsal flexion, mean knee varum angle, peak value of hip extension and range of pelvic rotation decreased; and knee flexion at initial contact, hip adduction angle, mean pelvic anterior tilt and mean pelvic obliquity increased on the loaded side relative to the unloaded side and unloaded walking. Decreased maximum hip extension during late stance, increased hip adduction, elevated pelvis and increased anterior pelvic tilt were seen on the loaded side and the pelvis was lowered, ankle dorsal flexion increased and the hip was abducted on the unloaded side as a counter effect.

Conclusion: Both the unloaded and loaded sides were affected by asymmetrical backpack carriage. The biomechanical alterations seen in asymmetrical backpack carriage may put some extra load on the lumbar vertebral joints and altered frontal knee biomechanics contribute to low back pain and pathologies in the knee joint.

Key words: Asymmetric school bag carrying; backpack; gait analysis; kinematic analysis; loading.

Most children and adolescents carry backpacks to school each day, usually either over one or both shoulders. Up to 85% of the population commonly complains of back pain[1] with the cumulative prevalence of back pain in children and adolescents ranging across from 30 to 51% in the literature.[2] Age, a family history of back pain, back injury, a high-level of participation in sports, spinal alignment disorders, backpack weight and backpack carrying habits are factors associated with back pain.[2] Backpack usage habits have been suspected to be one of the causes for the rising prevalence of back pain in school children. Some studies

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Correspondence: Bahar Özgül, PT. Marmara Üniversitesi Sağlık Bilimleri Fakültesi, Cevizli, Kartal, İstanbul, Turkey.

Tel: +90 216 - 399 93 71 Ext. 1198 e-mail: fztbaharozgul@gmail.com

Submitted: May 4, 2011 **Accepted:** February 2, 2012

Available online at
www.aott.org.tr
doi:10.3944/AOTT.2012.2678
QR (Quick Response) Code:

indicate asymmetrical backpack carrying method as one of the risks of back pain in these age groups.[3-5] It is not known whether back pain in childhood predicts back pain in adulthood.

In the United States, elementary school students are reported to carry on average a backpack load of 14 to 17% of their body weight (BW).[6] In Italy, the average backpack weight for school students is 22% of BW, reaching beyond 30% of BW once a week in a third of students.[3] A recent study by Chow et al. showed statistically significant effects of back loading, including reduced walking speed, altered joint motion and greater joint moments and powers in the gait of adolescent girls.[7] Additionally, Hong et al. reported marked effects on the kinematics and kinetics during activities, such as the use of a treadmill,[8] prolonged walking,[9] and stair climbing[10] with back loading in children.

Goodgold et al. indicated that 80% of the 345 children they surveyed reported carrying their backpack over two shoulders.[11] The incidence of wearing only 1 strap was 29.3% in New Zealand[12] and 10% in a cross-sectional study of 1,269 high-school-aged children in Australia.[13] In contrast, a study by Pascoe et al. showed that 73.4% of the children in their study used only 1 strap.[14] Goodgold and Nielsen found that only 57% of their subjects used backpacks correctly although they had received education on the correct technique in a school-based backpack health promotion program.[15]

Cottalorda et al.[16] examined the effects of carrying a backpack of 10 kg over one or two shoulders on ground reaction forces, stride length, stance, double stance and a symmetry index in 41 children with an average age of 12 years. Significant differences were found in average vertical force and maximum peaks of breaking and take off phases between the baseline and carrying the backpack on one or two shoulders. No difference was found between one and two shoulder carrying. This study also reported no significant difference between one and two shoulder carrying in gait parameters of stride length, stance and double support periods or symmetry, although the children were found to have longer stance, double support times and increases in stride length when walking with a backpack as compared with walking without a backpack.

In contrast, Pascoe et al. found that stride length decreased whereas stride frequency increased when subjects, aged between 11 to 13 years, wore backpacks.[14] However, they also reported that carrying the backpack on one shoulder promoted lateral spine bending and shoulder elevation leading to the conclusion that carrying backpacks on one shoulder significantly altered posture and gait parameters in adolescent children.

The Academy of Pediatrics recommends that a backpack should not contain more than 10% to 20% of a child's BW.[17] Although Negrini et al.[3] found that the average load carried in a backpack by school children was 22% of their BW, we followed the range recommended by the American Academy of Pediatrics. Considering previous research,[3,11] we used 15% of BW as this percentage is between recommendations and what is actually carried by students.

While most studies on backpacks have focused on adult use for recreational hiking, industrial applications or military soldiers,[18] only a few have investigated the effects of backpacks in children or adolescents.[3,4,19]

The aim of the present study was to investigate the biomechanical alterations during walking with asymmetric backpack carrying in adolescents, focusing on the influence of asymmetrical backpack carriage on kinematic parameters of both the loaded and unloaded lower extremities.

Patients and methods

Our study was carried out in the Istanbul University Faculty of Medicine, Department of Orthopedics and Traumatology Department Gait Analysis Laboratory between the June 2009 and July 2010 on 20 adolescent (male; mean age: 13±1.2 years) school children. Markers were located on the bodies according to the Helen Hayes protocol.[20] The experimental procedure was approved by the Hacettepe University Medical Ethics Committee (dated 08/13/2009, no. HEK 09/138).

Carried backpacks weighed 15% the subject's BW. The side of carriage was determined by the subject arbitrarily. Subjects were analyzed walking with no backpack (NoBP) and with the backpack carried on one shoulder (AsBP) of their choosing in a random sequence (Table 1). The mean values of 3 trials were analyzed by considering specific points of gait cycle in each subject.

Specific kinematic parameters were ankle range of motion (ROM), ankle dorsal flexion at initial contact, ankle peak dorsal flexion, ankle peak plantar flexion, knee ROM, knee flexion at initial contact, knee peak flexion, knee peak extension, knee valgum-varum

Table 1. Physical characteristics of the subjects.

	Age (years)	Mass (kg)	Height (cm)
Mean (SD)	13.45 (1.2)	47.25 (11.2)	157.35 (8.9)
Range	12-16	31-71	140-173

ROM, mean knee valgum-varum at stance phase, hip ROM, hip peak flexion, hip peak extension, hip rotation, hip abduction-adduction, pelvic tilt ROM, mean pelvic tilt at stance phase, pelvic rotation ROM, mean pelvic rotation at stance phase, pelvic obliquity ROM and mean pelvic obliquity at stance phase.

Kinematic parameters of the subject's gait at a self-selected speed were analyzed using a six-camera motion analysis system (Elite Clinic; BTS SpA, Milan, Italy) and two force plates (Kistler Instrumente AG, Winterthur, Switzerland).

Statistical differences between two conditions were analyzed with the paired t-test. Significance level was set at p<0.05.

Results

Peak ankle dorsal flexion, mean knee varum angle, peak value of hip extension and range of pelvic rotation decreased while knee flexion at initial contact; mean pelvic anterior tilt, and mean pelvic obliquity increased on the loaded side relative to the unloaded side during walking. Mean values and standard deviations in the conditions with and without backpack are shown in Table 2.

Ankle peak dorsal flexion increased significantly on the unloaded side and decreased on the loaded side (p<0.05) (Fig. 1).

In the frontal plane, knee kinematics was also affected by AsBP loading. Mean knee varum value increased significantly on the unloaded side but decreased on the loaded side relative to the unloaded gait (p<0.05) (Fig. 2). In the sagittal plane, knee flexion increased significantly at initial contact on the loaded side relative to both the unloaded side and unloaded walking (p<0.05) (Fig. 3).

In the hip joint, the maximum extension angle decreased on the loaded side compared to the unloaded side (p<0.05) (Fig. 4). There was no significant difference relative to unloaded gait. Mean hip adduction significantly increased on the loaded side and decreased on the unloaded side (p<0.05) (Fig. 5).

In the pelvis, mean anterior pelvic tilt during stance increased significantly on the loaded side (p<0.05) (Fig 6). Excursion of pelvis in the coronal plane decreased on the loaded and unloaded sides significantly relative to an unloaded gait (p<0.05) (Fig. 7). The loaded side pelvis was elevated and the unloaded side was significantly depressed (p<0.05) (Fig. 8).

Table 2. Mean values and standard deviations of the investigated gait parameters.

	Unloaded condition	Loaded side	Unloaded side
Ankle range of motion (ROM)	20.57±3.26	20.59±4.50	20.87±3.62
Ankle dorsal flexion at initial contact	-0.21±2.85	1.48±3.85	0.22±4.31
Ankle peak dorsal flexion	12.66±2.75	20.59±4.50*	20.87±3.62[†]
Ankle peak plantar flexion	-7.90±4.56	-9.03±4.67	-7.51±5.21
Knee ROM	57.46±4.37	56.80±5.25	58.20±4.86
Knee flexion at initial contact	9.72±4.14	12.52±5.31*	9.56±5.50[‡]
Knee peak flexion	63.12±4.67	63.89±6.13	62.76±5.33
Knee peak extension	5.65±3.92	7.09±6.49	4.56±5.02
Knee valgum-varum ROM	8.78±3.75	8.55±3.45	9.50±4.33
Mean knee valgum-varum at stance phase	5.30±2.63	4.14±3.78*	6.39±2.40[†,‡]
Hip ROM	41.59±3.19	42.44±3.79	43.13±3.33
Hip peak flexion	35.07±5.83	38.48±6.72	36.81±6.71
Hip peak extension	-6.52±6.95	-3.96±7.57	-6.32±7.04[‡]
Mean hip rotation at stance phase	2.67±7.88	1.46±9.62	4.74±9.98
Mean hip adduction at stance phase	-1.35±1.95	1.55±2.73*	-3.39±3.52[†,‡]
Pelvic tilt ROM	2.05±0.78	2.65±1.01	2.67±0.70
Mean pelvic tilt at stance phase	7.60±4.25	8.89±4.50*	8.90±4.58[†]
Pelvic rotation ROM	9.33±3.27	7.44±3.32*	7.97±3.34[†]
Mean pelvic rotation at stance phase	0.05±0.63	0.18±3.79	-0.83±3.55
Pelvic obliquity ROM	5.02±1.80	4.69±1.70	4.99±1.75
Mean pelvic obliquity at stance phase	0.16±0.38	2.40±2.08*	-1.46±2.34[†,‡]

*Statistically significant difference between unloaded condition and loaded side in the loaded condition (p<0.05).

[†] Statistically significant difference between unloaded condition and unloaded side in the loaded condition (p<0.05).

[‡] Statistically significant difference between loaded side and unloaded side in the loaded condition (p<0.05).

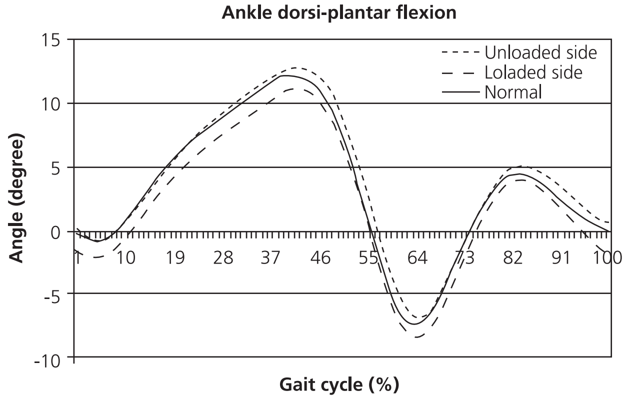

Fig. 1. Ankle sagittal angle during walking. There is significant difference between unloaded and loaded sides in peak dorsal flexion ($p<0.05$).

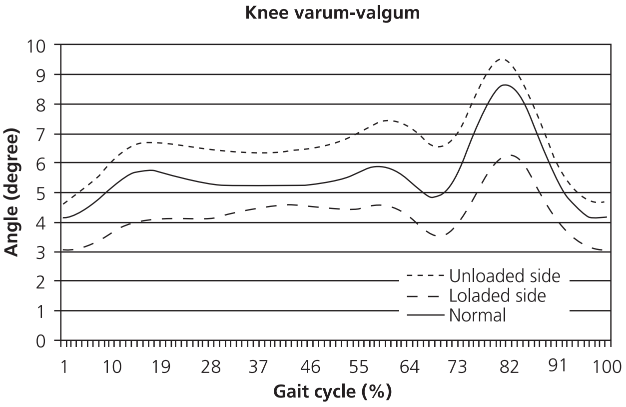

Fig. 2. There is significant difference between all conditions in mean knee varum-valgum at stance phase.

Discussion

The present study showed kinematic changes on the loaded side as well as some unexpected biomechanical alterations on the unloaded side.

In the ankle joint, the increase in peak ankle dorsal flexion on the unloaded side and the decrease in the loaded side may be related to energy production while carrying the backpack (Fig. 1). As the plantar flexor muscles are a main energy generator,[21] the main demand of energy should be produced from the loaded side. Therefore, decreased ankle dorsal flexion which means increased plantar flexion may be related to the increasing demand of the plantar flexor moment during forward progression.[22] In the same sense, increased ankle dorsal flexion on the unloaded side may be related with lower plantar flexor moment because of the decreased loading behavior relative to the loaded side. This interpretation may be confirmed by analyzing kinetic parameters.

The knee is flexed more at initial contact with a loaded gait than an unloaded one, which may have a relation with the shock absorption mechanism (Fig. 3). This also may cause knee flexor tightness and or discomfort on knee extension such as anterior knee pain during running or jumping. Frontal plane knee stability was disturbed significantly by asymmetric backpack carriage (Fig. 2). Typical varum behavior increased on the unloaded side and decreased on the loaded side and can alter the normal loading distribution on the medial and lateral compartments of the tibiofemoral joint. In other words, the knee had a more valgum pattern on the loaded side relative to the unloaded side. This is consistent with the literature.[23] This biomechanically altered loading pattern can cause cartilage degeneration in time.

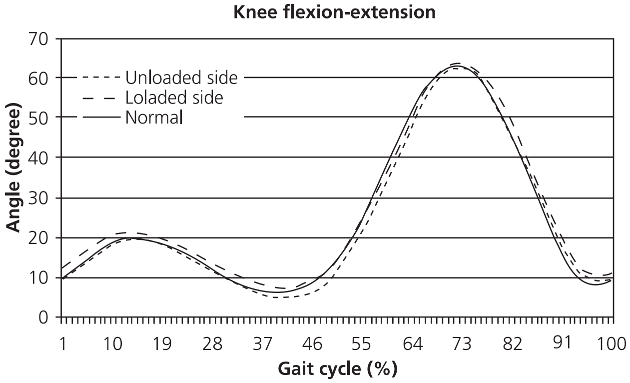

Fig. 3. Flexion-extension assessment of the knee. There are significant differences between no load and loaded side, and loaded side and unloaded side at initial contact value.

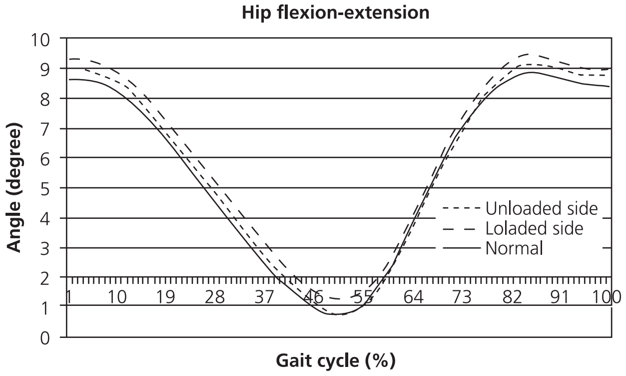

Fig. 4. Flexion-extension assessment of the hip. Statistically significant difference between unloaded and loaded side in peak extension is seen ($p<0.05$).

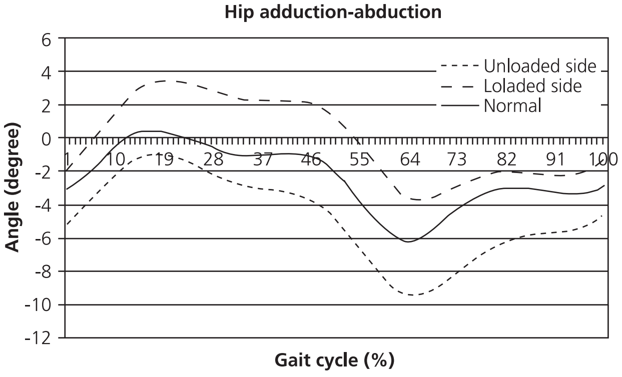

Fig. 5. All conditions are statistically different in mean hip adduction-abduction at stance phase.

Peak hip extension decreased in the late stance phase with increasing anterior pelvic tilt on the loaded side (Figs. 4 and 6). The increased hip flexion supported by increased knee (Fig. 3) and ankle plantar flexion (Fig. 1) may shorten hip flexor muscles, increase lumbar lordosis and put tension on the gastrocnemius muscles. The behavior of muscle length and moment should be interpreted by dynamic electromyography and kinetic analysis. Decreased hip extension may also be a part of the loading pattern and single limb stance stability. The load can be absorbed by flexing the hip and knee. Ground reaction force can pass behind the knee and in front of the hip as we see in children with cerebral palsy in a crouch gait.[24] Hip adduction increased with a levitated pelvis on the loaded side. Hip adduction with pelvic elevation on the loaded side and hip abduction with pelvic depression on the contralateral side was observed (Fig. 5).

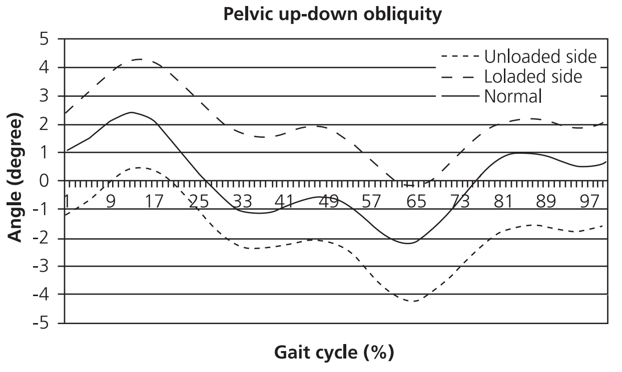

Fig. 7. Pelvic internal-external rotation values were significantly different between no load and loaded side, and no load and unloaded side for ROM.

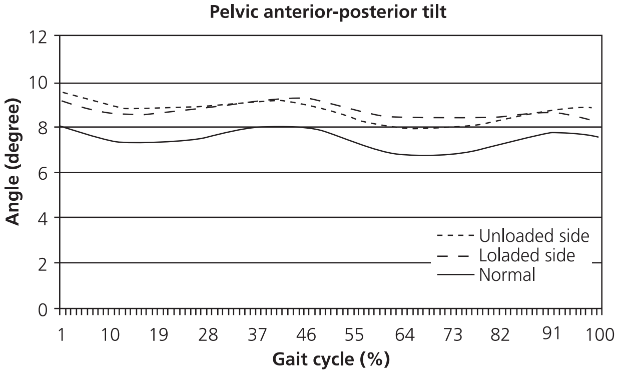

Fig. 6. Significant difference between no load and loaded side, and no load and unloaded side is seen in mean pelvic anterior-posterior tilt during stance.

The excursion of pelvic rotation was reduced on the loaded side (Fig. 7). This may be related with a demand for rotational stability of the pelvis and trunk. Decreasing rotational range may reduce the energy expenditure, prevent excessive bag swing and provide stability.

All subjects chose to carry their bags on the dominant sides. Accordingly, data was analyzed comparing the dominant and non-dominant side in the loaded condition. All subjects may have preferred to carry their bags on their dominant side because they felt more stable doing so.

The main limitation of this study was that it only focused on kinematical parameters. A more comprehensive study analyzing temporospatial parameters, kinetics and dynamic electromyography should be taken into consideration. In addition, the contribution of the trunk and upper limb should be analyzed.

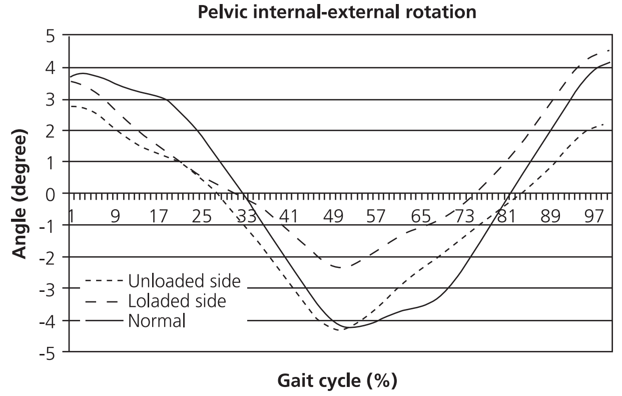

Fig. 8. Mean pelvic up-down obliquity was found statistically different between all conditions during stance phase.

In conclusion, both the unloaded and loaded sides were biomechanically affected by asymmetrical backpack carriage in adolescents. Biomechanical alterations in the ankle, knee, hip and pelvis may contribute to cartilage and soft tissue degeneration and, in time, cause ligament injuries, osteoarthritis and pain.

Conflicts of Interest: No conflicts declared.

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