Original research papers

EFFECT OF TWO BACKPACK DESIGNS ON COP DISPLACEMENT AND PLANTAR FORCE DISTRIBUTION IN CHILDREN DURING UPRIGHT STANCE

ANDRZEJ MASTALERZ[1], TOMASZ NIŹNIKOWSKI[2], MARIUSZ BUSZTA[3], PAWEŁ RÓŻAŃSKI[4], PAWEŁ WIŚNIOWSKI[5], JERZY SADOWSKI[2]

Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education, Department of Biomechanics[1], Faculty of Physical Education and Sport in Biała Podlaska, Department of Theory and Technology of Sports Training[2], Department of Foreign Languages[3], Department of Uniformed Services and Combat Sports[4], Faculty of Tourism and Health in Biała Podlaska, Department of Fundamentals of Physiotherapy[5]

Mailing address: Andrzej Mastalerz, Józef Piłsudski University of Physical Education, Department of Biomechanics, 34 Marymoncka Street, 00-968 Warsaw, tel.: +48 22 8340431 ext. 396, fax: +48 22 8651080, e-mail: andrzej.mastalerz@awf.edu.pl

Abstract
Introduction. Many studies have compared different backpack designs and their influence on the carrier; however, no data referring to school students aged 7-8 years are currently available. Therefore, the aim of the research was to assess the influence of backpack design on centre of pressure (COP) displacement and plantar force distribution in children during an upright stance. ***Material and methods.*** Nineteen school students (9 males and 10 females) volunteered for the study. Two Polish backpacks intended for school use were evaluated: backpack A, which had two main compartments, and backpack B, which had one main compartment. The backpack load was composed of books, binders, and regular school equipment. During the measurements, the subjects were asked to look ahead with the head straight and arms at the sides in a comfortable position and to stand barefoot on the F-Scan® sensors (Tekscan, F-Scan®) attached to the force platform (Kistler), carrying a load corresponding to 10% of their body mass. ***Results.*** The study found insignificant differences between the two backpack designs. Moreover, COP parameters increased significantly during an upright stance while carrying backpack B in comparison to the empty backpack condition. Additionally, we observed significantly higher values of plantar force distribution in the heel region for the condition without load and insignificantly higher ones for carrying backpack A. ***Conclusions.*** The results of the current study suggest that the differences between the two backpack designs are too marginal to be detected through COP displacement. Disturbances in plantar force distribution suggest a lack of posture control and a lower stability of the standing position with a backpack, but these disturbances were significant only when the backpack with one main compartment was used.

Key words: backpack, plantar pressure distribution, balance, children

Introduction

There is no unequivocal evidence that back pain is connected with carrying a backpack. However, heavy backpacks are commonly used by children and youth who attend school, and backpack load can constitute as much as 30%-40% of a child's body mass. Back pain usually occurs in girls aged 12-13 and boys aged 13-14 years [1], that is at an age associated with increased growth at puberty. Research carried out in Italy in 1999 (237 children, mean age = 11.7 years) revealed that low back pain was linked to backpack load. The study showed that one-third of the children carried a load greater than 30% of their body mass, 80% of the study participants sometimes experienced back pain, 65.7% of the subjects experienced fatigue when carrying backpacks, and 46.1% felt back pain related to carrying backpacks [2]. Cottalorda et al. [3] and Pascoe et al. [4] examined school children (mean age = 12 years) while they were walking with backpacks. The children performed the following activities: walking without a backpack, walking with a backpack on both shoulders, and walking with a backpack on one shoulder. They observed that carrying a backpack in an inappropriate manner (with one strap on the shoulder) led to abnormal spinal curvatures. Hong and Brueggemann [5] investigated the gait pattern, heart rate, and blood pressure of 410 boys aged 10. The boys carried backpacks without load and then backpacks that weighed 10%, 15%, and 20% of their body mass. The comparison between backpacks without load and backpacks that made up 10% of the children's body mass revealed no significant differences in the examined parameters. In the case of backpacks weighing 15% and 20% of the body mass, a significant irregular body inclination to the front was noted. Hong and Brueggemann [5] concluded that backpack load in 10-year-old boys should not exceed 10% of their body mass. Viry et al. [6] found that children carrying backpacks that exceed 20% of their body mass are exposed to a greater risk of back pain requiring medical assistance in their final school year. The authors [6] also noted a greater risk of back pain that led to absence from school or sports classes in children who carried their schoolbags by hand rather than on both shoulders. Grimmer and Williams [7] stated that in terms of body mass, children with back pain carried heavier backpacks than those who did not experience any back pain. Moreover, they revealed that this effect correlated with back pain more in the group of boys than in the group of girls. Pascoe et al. [4] showed that children aged 11-13 years carried book bags that weighed 17% of their body mass. Negrini et al. [2] checked the backpack load in Italian school children and estimated that the mean backpack load was 9.3 kg (with a maximum load of 12.5 kg, i.e. 22% of the children's body mass). Furthermore, 34.8% of the children carried a backpack load exceeding 30% of their body mass at least once a week. Viry et al. [6] made similar observations: in their study, the mean backpack load was 9.6 kg (in the range of 2-17 kg), which constituted an average of 19.2% of the children's body mass (in the range of 4-38%).

Due to concerns regarding the musculoskeletal health of school students, several backpack manufacturers have developed backpacks specifically designed for school use. Many studies have compared different backpack designs and their influence on the carrier [8, 9, 10, 11, 12]. However, there are no data referring to school students aged 7-8 years. Therefore, the aim of the research was to assess the influence of backpack design on centre of pressure (COP) displacement and plantar pressure distribution in children during an upright stance.

Material and methods

Nineteen school students (9 males and 10 females; mean age = 7.37 ± 0.28 years, height = 1.32 ± 0.06 m, weight = 26.9 ± 3.8 kg) volunteered for the study. Two Polish backpacks intended for school use were evaluated: backpack A, which had two main compartments, and backpack B, which had one main compartment. Both backpacks were supplied with a comprehensive back padding system and compression straps.

In order to investigate the effect of backpack design, we selected the following three conditions for our analysis: carrying an empty backpack (C) and carrying backpacks A and B with shoulder straps only. Two 20-second acquisitions were recorded. The mean value of the two trials under each condition was calculated. The backpack load was composed of books, binders, and normal school equipment. The total weight of the backpack load was the same for backpacks A and B.

During the measurements, the subjects were asked to look ahead with the head straight and arms at the sides in a comfortable position and to stand barefoot on the F-Scan® sensors (Tekscan, F-Scan® system, version 6.70, sensitivity range of sensor foil = 345-862 kPa, sensor density = 3.9 per cm^2 sampling rate = 169 Hz) attached to the force platform (Kistler, Type 2812A1-3, BioWare software v. 3.23, sampling rate = 20 Hz), carrying a load corresponding to 10% of their body mass.

Data from the force platform were processed to obtain postural parameters characterising COP displacements. The following parameters in the antero-posterior (AP) and medio-lateral (ML) axes were analysed: maximum excursion of COP along the axes (R_{AP} and R_{ML}), mean velocity of COP displacements along the axes (MV_{AP} and MV_{ML}), and total displacement of COP (S). The F-Scan® system was used to acquire data on relative loading while standing. The data were analysed by exporting 2 sets of force files (left and right foot) that were used to create a Force vs. Time plot for each of the 3 foot sole regions presented in figure 1 (total contact area (A), heel (H), and forefoot (F)).

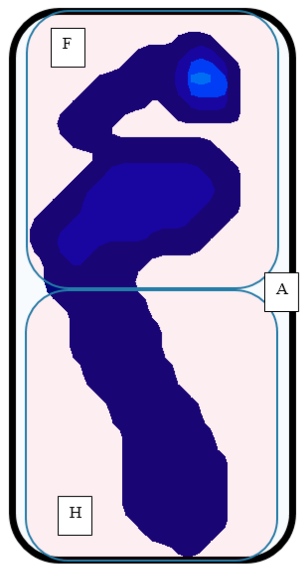

Figure 1. Areas investigated during the measurements: total contact area (A), heel (H), and forefoot (F)

Statistical analysis

Normality of distribution was assessed using the Shapiro-Wilk test (StatSoft, Inc. STATISTICA version 8.0) and a non-normal distribution was found. All differences between conditions were calculated using the Wilcoxon test and Friedman's ANOVA.

Results

ANOVA proved the effect of condition only for MV_{ML} (Chi-square (19, 2) = 7.052, $p < 0.029$), R_{AP} (Chi-square (19, 2) = 14.480, $p < 0.001$), and R_{ML} (Chi-square (19, 2) = 31.547, $p < 0.001$).

The data presented in table 1 show differences between backpacks only for the R_{AP} and R_{ML} parameters. Moreover, COP parameters increased significantly during an upright stance while carrying backpack B in comparison to the empty backpack condition. Additionally, R_{ML} was significantly higher for all conditions ($p < 0.01$).

Table 1. Mean values ± SD of COP parameters for different conditions (A, B, and C)

	MV_{ML}[mm/s]	MV_{AP}[mm/s]	R_{ML}[mm]	R_{AP}[mm]	S[mm]
A	19.2 ± 5	21.9 ± 4.1	26.5 ± 7.8[a.b]	23 ± 8.9[a.b]	646.7 ± 131.8
B	21.6 ± 6[a]	23.2 ± 5.9[a]	30.4 ± 9.4[aa]	29.2 ± 29.5[a]	702.7 ± 174.7[a]
C	18.1 ± 4.3	20.3 ± 3.6	24.5 ± 6.7	22.3 ± 9.9	599.3 ±1 12.9

[a] = differs significantly from condition C; [b] = differs significantly from condition B.

Data collected using F-Scan® flexible insole sensors were converted into percentage differences in plantar pressure distribution (tab. 2) connected with the distribution of pressure on the right (F_R) and left (F_L) foot and into the distribution regarding the forefoot (F_F) and hindfoot (F_H). ANOVA proved the effect of condition only for F_F (Chi-square (19, 2) = 15.022, $p < 0.001$) and F_H (Chi-square (19, 2) = 14.800, $p < 0.001$). Additionally, the analysis revealed significantly higher values of plantar force distribution for F_H when standing without load ($p < 0.001$) and insignificantly higher values of this distribution when standing with backpack A. A shift of plantar force to the toes was found for backpack B only. A bipedal position with no load showed greater force on the left foot as well as in all backpack conditions.

Table 2. Mean values ± SD of force distribution on the left (F_L) and right (F_R) foot as well as on the heel (F_H) and forefoot (F_F)

	F_L [%]	F_R [%]	F_H [%]	F_F [%]
A	0.55 ± 0.04	0.45 ± 0.04	0.52 ± 0.05[a]	0.48 ± 0.05[a]
B	0.54 ± 0.06	0.46 ± 0.03	0.49 ± 0.03[a]	0.51 ± 0.05[a]
C	0.52 ± 0.05	0.48 ± 0.05	0.65 ± 0.06	0.35 ± 0.04[b]

[a] = differs significantly from condition C; [b] = significant difference between heel and forefoot.

Discussion

Mean posture parameters showed no significant differences between backpack designs in the current study. Research available in the literature has found that variations in backpack design often result in changes in posture and other parameters. Backpacks that include two main compartments have been observed to cause significant differences in gait in comparison to standard backpacks [13]. These differences have to do with better load distribution, which is much closer to the centre of body mass [13]. The results of our study suggest that the differences between the two backpack designs are too marginal to be detected through COP displacement. Significant differences were observed only for maximum excursion of COP in both axes. It may be assumed that the load distributions of the two backpacks were quite similar. The lack of more significant differences between backpack designs in this study may be attributed to the position of the load on the back. Brackley et al. [14] found that loads should be placed lower on the spine in order to minimise children's postural adaptations, whereas the two backpack designs (A and B) used in our study make it possible to support the loads using shoulder straps only. Unfortunately, additional compartments did not result in the load being located closer to the centre of mass.

Another important observation made when analysing the influence of the loads concerned force distribution in different plantar regions. As far as the stances without load and with backpack A are concerned, our data coincide with what was observed by Cavanagh et al. [15], who evaluated 107 normal adult individuals and found that 60.5% of their body weight fell on the heel, 7.8% on the midfoot, 28.1% on the forefoot, and 3.6% on the toes. However, our findings are that when the subjects were standing with backpack B, plantar force distribution of the forefoot region was greater than that of the heel region. As for backpack A, even though the load did not lead to the reversal of the above-mentioned proportion, we found a significant increase in the load in the forefoot region. Such a clear tendency was not observed by Rodrigues et al. [16], which may be explained by a lower age of the population examined in this study. Another factor that could influence such significant displacement of plantar force distribution on the forefeet while carrying both backpacks might be the lack of mechanisms of body posture control that can be developed though motor experience. Muratori et al. [17] stated that motor learning occurs when processes associated with practice favour the capacity to produce a skilful action from interactions between perception, cognition, and action while performing a task that interacts with the environment. When a task is carried out functionally, it means that a new strategy for perception and action has been constructed. In children beginning their school education, the danger that stems from the lack of control in maintaining a correct body posture when load is applied in the form of a school backpack might cause abnormal spinal curvatures, overload, as well as pain. Moreover, in our study, carrying a load corresponding with that of a normal school backpack resulted in a lower stability of the standing position because the external load was shifted to the toes.

Conclusions

The results of the current study suggest that the differences between the two backpack designs examined are too marginal to be detected through COP displacement. Disturbances in plantar force distribution during an upright stance with a backpack suggest a lack of posture control and lower stability of the standing position. This means that both backpacks had an influence on the regulatory mechanism of posture control, because plantar force distribution had been shifted to the toes, and, in general, the toes are only minimally involved in the weight-bearing process [15]. Accordingly, it should be emphasised that the mechanism was significant only when the backpack with one main compartment was used.

Acknowledgements

The study was supported by the Polish Ministry of Science and Higher Education as a statutory activity project of the Józef Piłsudski University of Physical Education, Faculty of Physical Education and Sport in Biała Podlaska (Project No. DS-169). The experimental data were gathered in the Laboratory of Human Motion Modeling and Ergonomics in the Regional Centre of Research and Development in Biała Podlaska co-financed under the European Regional Development Fund, Operational Programme Development of Eastern Poland 2007-2013.

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Submitted: August 25, 2016
Accepted: September 14, 2016