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Plantar force distribution and pressure center oscillation in relation to the weight and positioning of school supplies and books in student's backpack

Distribuição da força plantar e oscilação do centro de pressão em relação ao peso e posicionamento do material escolar

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Abstract

Objective: The influence of the weight and positioning of school supplies and books in backpacks, on plantar force distribution (PFD) and pressure center location, was investigated among students. **Methods:** Thirty volunteers of both genders participated in the study. Their mean age was 10.76 (± 1.35) years and none of them had postural abnormalities. Baropodometric data were collected using a computerized baropodometric system (Matscan Research, Tekscan®, 5.72): without load (control) and with loads of 5, 10 and 15% of body weight in a backpack, positioned on the back, on the chest and on the right and left shoulders. **Results:** The PFD without load was greater on the left heel than on the right heel ($p< 0.05$). With a load of 10% on the left shoulder, the PFD was greater on the right and smaller on the left foot, in comparison with the control ($p< 0.05$). With a load of 5% on the back, the PFD was smaller on the right midfoot (RMF) and left forefoot (lff); with 10%, it was smaller on the RMF and left midfoot (LMF) and greater on the right toes (RT); with 15%, it was smaller on the RMF and greater on the RT ($p< 0.05$). The plantar force was greater on the RT with loads of 10% and 15% than it was with loads of 5% ($p< 0.05$). With loads of 15% on the back and on the chest, the pressure center displacement was greater than with a load of 5% ($p< 0.05$). The PFD was not influenced by the different loads and backpack positions. **Conclusions:** Taking into consideration the increased pressure center displacement with a load of 15%, it is recommended that school backpack loads should not exceed 10% of body mass. Investigations on posture adaptations to different loads and backpack positions are suggested, in order to detect possible abnormalities and propose preventive actions.

Key words: plantar force; pressure center oscillation; schoolchildren.

Resumo

Objetivo: Investigou-se a influência da carga e posicionamento do material escolar sobre a distribuição da força plantar (DFP) e trajetória do centro de pressão (COP) em estudantes. **Métodos:** Participaram 30 voluntários (10,7 ± 1,35 anos), ambos os gêneros, sem alteração postural. Dados baropodométricos foram coletados em sistema de baropodometria computadorizada (Matscan Research, Teckscan®, 5.72): sem carga (controle); com carga (mochila) de 5, 10 e 15% da massa corporal, posicionada nas regiões anterior e posterior do tronco, ombro direito e esquerdo. **Resultados:** Sem carga, a DFP foi maior no calcâneo esquerdo comparado ao direito ($p< 0,05$). Com carga de 10% no ombro esquerdo, a DFP foi maior à direita e menor à esquerda, comparado ao controle ($p< 0,05$). Com 5% na região posterior do tronco, a DFP foi menor no médio-pé direito (mpD) e antepé esquerdo (apE); com 10%, foi menor no mpD e mpE e maior no artelho direito (atD); com 15%, foi menor no mpD e maior no atD ($p< 0,05$). A força plantar foi maior no atD com carga de 10 e 15% em relação a 5% ($p< 0,05$). Com carga de 15% nas regiões anterior e posterior do tronco, a trajetória do COP foi maior ($p< 0,05$) comparada à carga de 5%. A DFP não foi influenciada pelas diferentes cargas e posições da mochila. **Conclusões:** Considerando o aumento da trajetória do COP com carga de 15%, recomenda-se que a carga das mochilas escolares não ultrapasse 10% da massa corporal. Sugere-se investigação das adaptações da postura às diferentes cargas e posições da mochila, visando detectar possíveis alterações e propor ações preventivas.

Palavras-chave: força plantar; oscilação do centro de pressão; escolares.

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Introduction

Children and adolescents perform a daily routine of carrying school material over their elementary and middle school years. These phases of education correspond to to the ages between 7 and 14 years. Girls demonstrate a “growth peak” at a mean age of 12 and boys, at approximately 14 years[1,2]. During this growth period, the vertebral column becomes more susceptible to external influences, especially to loads that are imposed on it, and shows the possibility of suffering lateral and anteroposterior dislocations[3].

Considering that backpacks are practical and are the most commonly used means of carrying school material[4-8], taking care with the load and the way in which it is supported is fundamental for this age group. When the backpack load is greater than the support capacity of the muscle groups, there is an overload on the vertebral column[9], which may cause postural alterations, pain or dysfunctions. Since carrying school material is a daily routine that is repeated over consecutive years, special care is needed to avoid the presence of postural alterations that might become established over the medium to long term, thereby bringing risks to this population’s health[3,7,9].

Brackley and Stevenson[3] showed that, although epidemiological, physiological and biomechanical data in the literature justifies backpack load-carrying amounting to between 10 and 15% of body weight, this limit may not be sufficient to prevent musculoskeletal disorders, tissue lesions or low-back pain. This suggests that there is a need for studies investigating the different factors, which may influence the student’s vertebral column structure.

Homogeneous distribution of body weight on the plantar area provides adequate alignment to the pelvis and consequently to the vertebral column[10]. Therefore, the present study proposed to investigate whether the suggested load (10% to 15% of the body weight) and asymmetrical support for this load on the trunk could alter the plantar force distribution and the body’s pressure center pathway among elementary-level students. The influences of a load lower than the proposed values were also investigated in relation to these variables.

The presence of abnormalities in the plantar force distribution and in the body’s pressure center pathway may suggest that inadequate postures are being adopted when carrying school material. Over the long term, this would favor several vertebral column abnormalities. Such abnormalities may cause functional[11], psychosocial, work and quality-of-life[3] constraints, thus justifying the need for preventive intervention.

Material and methods

This was an analytical observational cross-sectional study, for which approval was granted by the Institutional Research Ethics Committee (Procedure no. 91/04). Thirty volunteers of both genders, with a mean age of 10.7 (±1.35) years, were recruited from state schools in the region. Their parents or the adults responsible for them signed a free and informed consent statement. The students who were included demonstrated normal results from postural evaluations, without any pain, histories of lower-limb injuries or neurological dysfunctions.

The volunteers were screened on the premises of these schools, using a standardized form for postural evaluation. Using a Symmetrigraf® and a plumb line, the students were evaluated wearing bikini/swim trunks. Those who demonstrated normal results from the postural evaluation were selected for the next stage, while those who showed any abnormalities in the vertebral column or misalignments/asymmetry in the anterior, posterior and/or lateral views, were referred for treatment.

Next, anthropometrical data (body weight and height) were obtained from the selected individuals and a lower-limb dominance test was applied, which consisted of asking the individuals to climb steps. The limb that was chosen for starting to go up was considered to be the dominant limb, as described by Gobbi, Secco and Marins[12]. Baropodometric data were collected using a computerized baropodometric system that consisted of a pressure platform (Matscan research software version 5.72, Tekscan®) connected to a microcomputer.

The volunteers were asked to remain in an orthostatic posture on the pressure platform, with bare feet and bipedally supported with their eyes open, so that the equipment could be calibrated for each data collection session and for the first reading (control data collection). They were then asked to position a standardized backpack containing 5%, 10% and 15% of each student’s body weight, in the following regions, for data collection: anterior of the trunk (A), posterior of the trunk (P), right (R) and left shoulder (L).

The backpack load was composed of magazines and sheets of paper that were weighed on a digital balance so that each individual’s load could be obtained. During the baropodometric data collection, three films of approximately seven seconds were recorded, in which the variations in force and pressure imposed on the plantar surface during the whole data collection period were filed in the program, thus obtaining a mean value for each parameter analyzed.

The sequence of loads in the backpack was randomly defined so that there was no adaptation to progressive loads. The variables chosen for analysis were plantar force and the body’s pressure center pathway. Plantar force was analyzed according to backpack positioning. When the backpack was positioned in the anterior and posterior regions of the trunk, the plantar force distribution was observed in four regions of the foot: heel, midfoot, forefoot and toes. When positioned on the right and left shoulders, the force distribution was considered over the whole plantar area. The body's pressure center pathway was obtained by selecting in the program the option *Save Center of Force*. The pressure center oscillation was thus recorded for subsequent quantification.

The Shapiro-Wilk test was applied to investigate whether the variables demonstrated a normal distribution. Comparative analyses were then performed, applying the Student *t* test for paired data or the Wilcoxon test for variables that did not meet the assumption of normality. The statistical significance level was taken to be 5%. The analyses were processed in the SPSS 11.0 software (Statistical Package for the Social Sciences) and the Statistica 6 software.

Results

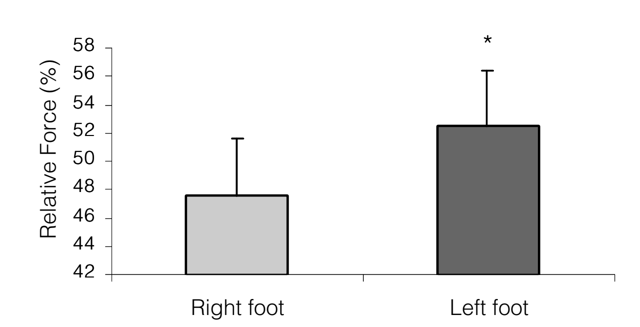
Plantar Force

The initial evaluation in a bipedal position with no load (control) showed greater force on the left foot (52.42% ± 4.02) than on the right (47.56% ± 4.03) ($p < 0.05$ – Figure 1). When the different loads were added to the right shoulder, the force values on the right and left foot, respectively, were 48.49% ± 6.08 and 50.34% ± 4.64, with a 5% load; 48.55% ± 5.89 and 51.40% ± 5.91, with a 10% load; and 48.36% ± 6.53 and 51.57% ± 6.57, with a 15% load. These were not different from the right control values (47.55% ± 4.03) and left control values (52.41% ± 4.02) ($p > 0.05$).

When a 10% body weight load was added to the left shoulder, there was an increase in plantar force on the right foot (48.73% ± 4.56) and a decrease on the left foot (51.22% ± 4.59), in comparison with the control ($p < 0.05$ – Figure 2).

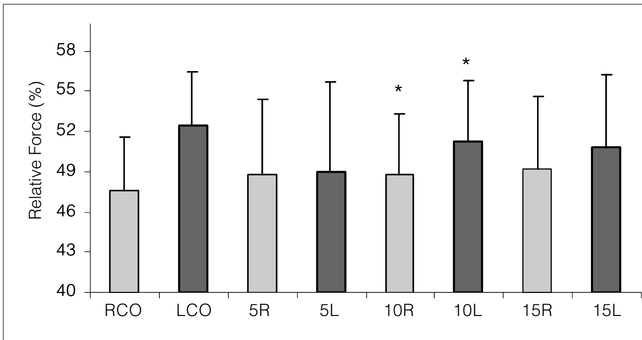
The plantar region that demonstrated the greatest overload in the bipedal position with no load (control) was the left heel, in relation to the right heel. When the backpack was positioned in the anterior region of the torso and the force distribution was evaluated in the different regions of the foot, the values that were obtained with 5, 10 and 15% body weight loads were not different from the control. There were also no significant differences when the values obtained with the different loads were compared between each other ($p > 0.05$ – Table 1).

Table 2 represents the force distribution in the different area of the feet when the backpack was supported on the posterior



(*) Differs significantly from mean for right foot.

Figure 1. Mean values ± SD for relative force on the right and left feet (control values).



(*) Differs significantly from means for CO.

Figure 2. Comparative mean values ± SD for relative force on the right (R) and left (L) feet, for the control (CO) and loads of 5%, 10% and 15%, with backpack positioned on left shoulder.

Table 1. Mean values ± SD for force distribution on different plantar regions: without load (control) and with loads of 5%, 10% and 15% of body weight, with the backpack placed on the anterior region of the trunk.

Plantar region	Control	5%	10%	15%
R heel	25.86 ± 8.82	26.06 ± 7.36	27.32 ± 6.98	25.5 ± 6.58
L heel	30.43 ± 5.84†	30.33 ± 7.24	31 ± 5.93	32.3 ± 6.33
R midfoot	8.40 ± 4.10	8.06 ± 3.61	7.56 ± 3.36	6.37 ± 3.36
L midfoot	7.68 ± 3.82	7.74 ± 3.66	6.81 ± 3.31	6.85 ± 3.08
R forefoot	11.70 ± 4.25	11.95 ± 3.61	11.34 ± 4.06	11.84 ± 4.33
L forefoot	12.54 ± 4.89	12.43 ± 5.3	11.78 ± 4.09	12.8 ± 4.05
R toes	1.63 ± 1.54	1.63 ± 1.3	1.73 ± 1.41	1.65 ± 1.4
L toes	1.73 ± 1.74	1.78 ± 1.61	1.69 ± 1.62	1.66 ± 1.61

R: right; L: left
† Differs significantly from the control right heel.

Table 2. Mean values ± SD for force distribution on different plantar regions: without load (control) and with loads of 5%, 10% and 15% of body weight, with the backpack placed on the posterior region of the trunk.

Plantar region	Control	5%	10%	15%
R heel	25.86 ± 8.82	26.40 ± 7.75	27.05 ± 7.07	26.31 ± 7.05
L heel	30.43 ± 5.84†	30.02 ± 5.42	30.97 ± 6.05	30.61 ± 6.79
R midfoot	8.40 ± 4.10	7.55 ± 3.86*	6.84 ± 3.19*	6.72 ± 3.27*
L midfoot	7.68 ± 3.82	7.35 ± 6.60	6.74 ± 313*	6.60 ± 3.67
R forefoot	11.70 ± 4.25	11.86 ± 4.11	12.03 ± 4.02	12.69 ± 4.63
L forefoot	12.54 ± 4.89	11.65 ± 3.43*	12.31 ± 3.67	12.13 ± 3.55
R toes	1.63 ± 1.54	1.54 ± 1.24	2.0 ± 1.74*#	1.85 ± 1.17*#
L toes	1.73 ± 1.74	1.59 ± 4.01	1.64 ± 1.48	1.83 ± 1.41

R: right; L: left;
* Differs significantly from the mean for the control; (#) Differs significantly from the mean for the right toes with 5% body weight load; (†) Differs significantly from the control right heel.

Table 3. Mean values ± SD for anteroposterior pathway of body's center of pressure, for the control and different backpack positions with loads of 5, 10 and 15% of body weight.

	Control	5%	10%	15%
	21.35 ± 1.8	- -	- -	- -
Posterior backpack	- -	21.24 ± 2.11	21.7 ± 1.75	21.96 ± 2.47*
Anterior backpack	- -	21.2 ± 1.88	21.57 ± 1.72	22.26 ± 2.34#
R shoulder backpack	- -	21.2 ± 2.07	21.51 ± 1.87	22.02 ± 2.67
L shoulder backpack	- -	21.43 ± 2.05	21.47 ± 1.7	21.22 ± 2.26

R: right; L: left;
* Differs significantly from the mean with posterior backpack 5%; (#) Differs significantly from the mean with anterior backpack 5%.

Table 4. Mean values ± SD for mediolateral pathway of body's center of pressure, for the control and different backpack positions with loads of 5, 10 and 15% of body weight.

	Control	5%	10%	15%
	14.95 ± 2.44	- -	- -	- -
Posterior backpack	- -	14.61 ± 2.0	14.49 ± 2.27	14.70 ± 1.98
Anterior backpack	- -	14.80 ± 1.90	14.40 ± 1.84	14.43 ± 2.03
R shoulder backpack	- -	14.41 ± 1.98	14.37 ± 2.05	14.33 ± 2.01
L shoulder backpack	- -	14.58 ± 1.89	14.12 ± 2.33	14.27 ± 2.09

R: right; L: left.

region of the trunk. For the 5% body weight load, there was a decrease in the force distribution to the right midfoot and left forefoot, in relation to the respective control values ($p < 0.05$). With the 10% load, there was a decrease in the force distribution to the right and left midfoot in relation to the respective control values ($p < 0.05$). When the load was 15%, there was a decrease in the force distribution to the right midfoot and an increase in the force distribution to the right toes, in relation to the control ($p < 0.05$). The relative force distribution to the right toes with 10% and 15% loads was greater than that with a 5% load ($p < 0.05$ – Table 2).

Pressure Center Pathway

Table 3 shows the values for the anteroposterior pressure center pathway with no load and when the backpack with different loads was positioned in the anterior and posterior regions of the trunk and on the right and left shoulders. It was observed that there was increased postural oscillation when the backpack with a 15% body weight load was positioned on the anterior and posterior regions of the trunk, in relation to the 5% load ($p < 0.05$).

Table 4 shows the values of the medial-lateral pressure center pathway. No significant differences were noted between the different positions and backpack loads and the control, or when comparing the loads with each other ($p > 0.05$).

Discussion

Backpacks are one of the means of carrying school material that is most used[4-8]. They are most commonly attached to the back, followed by scapular attachment[9,13]. The literature reveals a discussion about the load limit for backpacks, between 10 and 15% of the body weight. However, no scientifically justified specific value has been determined that presents no risk to any of the musculoskeletal structures[3].

Some authors have suggested that loads of 10% of body weight might not offer any risk, but state that further research must be carried out to cover all the variables involved[4,14,15]. Negrini and Carabalona[6] suggest a maximum limit of up to 15% of body weight. Nonetheless, such information is also not based on scientific data. Although there is a need for analysis of other variables that would make it possible to identify the specific way in which the load and method of carrying the school material influence students' posture, the data in the present study were obtained based on scientific criteria. The data show that there is asymmetry in the plantar force distribution and oscillation in the body's pressure center. These points can be considered in future studies, with the aim of drawing up primary prevention proposals for elementary and middle school students.

Considering that scoliosis is the most serious postural alteration among the studied populations[16], investigations of possible asymmetries in plantar force distribution caused by the habit of carrying inappropriately positioned and excessive loads of school material is important within the sphere of public health. Early identification of such asymmetries may give rise to preventive and corrective intervention actions to influence pelvis alignment and consequently, vertebral column alignment.

In the present study, the abnormality in plantar force distribution in the bipedal position with no load (control) was possibly related to lower limb dominance. Some studies have defined foot preference such that the preferred foot is the one used for manipulating an object or initiating a movement and the non-preferred foot is the one used for postural support[17].

Gobbi, Secco and Marins[12] proposed some tests for investigating lower limb dominance, such as kicking a ball, lifting an object made of foam or drawing a letter (static tests), and some dynamic tasks, such as directing a ball, aligning small balls or going around a hoop with a ball. In the present study, 29 volunteers (96.6%) demonstrated dominance of the right lower limb, which was investigated in accordance with the tests proposed by Gobbi, Secco and Marins[12]. The higher plantar force distribution on the left lower limb that was found could be related to postural support, as stated by Peters[17].

Although there were no significant differences in plantar force distribution when the backpack with different loads was positioned on the right shoulder, a tendency towards asymmetry was noted. This tendency could also be seen when the loads were added to the left shoulder. The greater symmetry after adding the loads was probably related to preexisting differences, thus making it impossible to reach conclusions regarding the influence of the load when positioned unilaterally on the shoulders.

Another important point from analyzing the influence of the loads was the force distribution in the different plantar regions. These forces were distributed heterogeneously in different regions of the foot, in the static posture. In the bipedal position with no load, the force distribution was 56.29% on the heel, 16.08% on the mid-foot, 24.24% on the forefoot and 3.36% on the toes. These data coincide with what was observed by Cavanagh, Rodgers and Liboshi[18], who evaluated 107 normal adult individuals, among whom 60.5% of the body weight fell on the heel, 7.8% on the midfoot, 28.1% on the forefoot and 3.6% on the toes.

When the backpack was positioned on the posterior region of the trunk with loads of 5%, 10% or 15% of body weight, there was the same tendency for plantar force distribution as in the control (with no load). The values, which were significant, did not alter the distributions, which were always greater on the heel and forefoot and smaller on the midfoot and toes. With a load, the tendency was for there to be greater symmetry between the right and left foot, in comparison with the control.

Studies carried out by Rebelatto, Caldas and De Vitta[9]; De Vitta, Madrigal and Sales[15]; Negrini, Carabalona and Sibila[14]; and Negrini and Carabalona[6] showed that children and adolescents carried large loads in their backpacks. The greatest concern is the consequences that this daily routine can bring to the musculoskeletal structures, over the medium and long term, considering that these individuals are in the middle of their skeletal development phase.

Postural control is influenced by learned motor experiences. Shummay-Cook and Woollacott[19] stated that motor learning is acquired when processes associated with practice favor 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 learned.

Considering that students perform the task of carrying school material every day for many years, it is possible that this motor ability has been incorporated into the students' habits and, consequently, fine adjustment of muscle activity has been achieved. This is because the plantar force distribution demonstrated behavior that was nearly symmetrical, even with larger loads and with less appropriate positioning of the backpack. These results indicated the need for detailed analyses of individuals' posture when different overloads are imposed.

Postural oscillation is related to postural control. The fact that there were no increases in this oscillation in the mediolateral direction in the presence of loads and different backpack positions may be related to adaptations of the central nervous system for the proposed task[19], which represents the daily routine for the volunteers. This may have favored maintenance of postural balance, even when the load was the maximum, therefore again suggesting the need for specific postural analysis.

It was concluded that the plantar force distribution was not influenced by the different loads and positions of the backpack. Considering the increases in the body's pressure center pathway caused by the load of 15% of body weight, symmetrically positioned in the anterior and posterior regions of the trunk, it is recommended that the maximum limit for loads carried in school backpacks should not exceed 10% of body weight.

It is emphasized that there is a need for studies to investigate possible postural adaptations to different loads and backpack positions, to aim at early identification of abnormalities and drawing up of preventive strategies, by means of working on health education that would cover elementary and middle school students, their families and the school's social body.

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