JOMH
Journal of Men's Health

J. Mens. Health **2022**; 18(5): 109
https://doi.org/10.31083/j.jomh1805109

Original Research

Effects of a modified backpack model on ground reaction forces in children of different ages during walking and running

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Submitted: 10 September 2021 Accepted: 17 November 2021 Published: 10 May 2022

Abstract

Background: Backpacks are widely used by children to carry different objects and the literature supports that most backpacks contain excessive weight. To minimize the loading effects (i.e., ground reaction force), modified backpacks have been tested. However, the effects of elastics on shoulders straps are yet to be studied. Thus, the aim of this study was to test and compare the effect on the vertical ground reaction force of a standard backpack with a modified one with elastic straps while walking and running. **Methods**: 9 children (5 boys and 4 girls) were included in the group G-5 (age: 11.0 $\pm$ 0.3 years-old; body mass: 35.3 $\pm$ 7.3 kg; height: 1.41 $\pm$ 0.1 m) and twelve (7 boys and 5 girls) in G-9 (age: 15.0 $\pm$ 0.7 years-old; body mass: 56.7 $\pm$ 11.2 kg; height: 1.63 $\pm$ 0.1 m). Participants attended a single session and were initially asked to walk and then run over a force plate. The software Ergotest MuscleLab v8.0 (MuscleLab, Ergotest Innovation, Porsgrunn, Norway) was linked to the force platform and was used to collect and export data. The level of statistical significance was set at $p \leq 0.05$. Additionally, the effect size of the differences verified on T-Tests was calculated based on Cohen's d. **Results**: Statistically significant differences between a common backpack and a modified one with straps ($p < 0.05$) were observed for the variables time and force when walking. Regarding the running condition, the time variable did not differ significantly between the backpacks. However, the force variable changed considerably between backpack types ($p < 0.05$). The new straps minimized the forces magnitude, resulting in lower stress. **Conclusions**: The modified backpacks with shoulder elastic straps reduced the ground reaction force and impact when walking and running. The study may encourage other researchers to assess the effects of different movements (such as jumping or rotating) on ground reaction force.

Keywords: backpacks; modified straps; ground reaction forces; locomotion

1. Introduction

Backpacks are widely used by children to carry books, notebooks, pencil holders, and pedagogic material. Most of the time, children have to carry the material daily from home to school and back due to the classes and homework activities [1,2]. The literature on the topic has raised concerns about heavy loads carried in backpacks by children [3–5], some relating them to health issues [1,6,7]. However, most of the concerns are associated with the effect of the backpack load on posture and gait patterns, such as reduced pelvic rotation [8]; increments on the angle of the head (an adopted forward position) [9–11]; excessive trunk flexion [9–11]; and an increase in ground reaction forces (GRF) [12–15]. These heavy backpacks may cause the above mentioned postural changes [4]. Additionally, backpacks influence the kinetics and kinematics of children's walking as the greater the schoolbag load, the slower will be the locomotion and the greater the mechanical load [16–18].

The mechanical forces influence vertebral growth [19] and high loading rates may have negative effects on bone health [20,21]. For instance, growing children who use backpacks daily may suffer high GRF level associated with lower-limb [22,23] and spinal injuries [24]. This leads to a health related problem as already presented in literature [25]. That may be explained by children's motor activities, such as running or jumping while carrying school backpacks [26]. Efforts have been made to define a load limit to be carried [2,27], which is most frequently set at 10% of the child's body weight (BW) [2,28,29]. However, this limit is often exceeded [3,28,30]. For example, recent studies found that approximately two-thirds of Portuguese children (10–15 years old) and Polish children (7–9 years old) usually carry loads above 15% of their body weight [4,5].

In order to minimize the effects of carrying heavy backpacks, several models of bags have been proposed. Some of the proposals promote a more upright posture by carrying the load in big pockets at the hip level [31] or replacing the flexible shoulder straps by rigid ones [31]. Interior pockets have also been developed for school backpacks to distribute the weight. The pocket placed near the chest level positively influenced the postural pattern, decreased head deviation [10], and the abdominals and spinal erectors muscular activity [32]. As mentioned before, the load stress is typically measured by the GRF. In an attempt to reduce the GRF peak values, Ren *et al*. [33] assessed the influence of decreasing suspension stiffness in military material (bags) on the GRFs peak values. The evaluation was performed using a computer simulation of level walking of a backpack suspension model with linear elastic and linear damping components.

Unfortunately, some of the attempts to create alternative backpack models that offer biomechanical and energetic advantages have not reached the market, due to not being fashionable and enjoyed by children. Adding elastic material to the shoulder straps of a common backpack will not change the backpack design much and has theoretical support [33]. Thus, it is important to explore and consider a traditional backpack design that can bring biomechanical advantages, specifically a positive influence on the GRF. Furthermore, backpack weight is not the same in the Portuguese primary education system [4,5] and children's physical characteristics also become different as they grow. Regarding the above mentioned information, it is important to understand how the backpack load affects the GRF of children aged between 10 and 15 years old (5th and 9th grade of the Portuguese educational system). Moreover, children usually play (walking and running) with the backpack on, and the GRF will vary according to the type of locomotion. Upon that, it is important to better understand the effect of walking and running on the GRF with a modified backpack. Therefore, the aim of this study was to test the effect of the vertical GRF in children when walking and running with both a common backpack and one with elastics added to the straps, allowing a decrease in the shoulder straps stiffness. It was hypothesized that the vertical GRF will be lower with the added elastics in the backpack compared to the one without them. Moreover, the walking may present a lower GRF compared to running.

2. Materials and methods

2.1 Participants

21 boys and girls were recruited to participate in this study. Children were grouped according to the Portuguese educational system. The 5th grade (G-5) represents the first year of the second cycle in the basic education system, and the 9th grade (G-9) the last year of the third cycle. 9 children (5 boys and 4 girls) were included in G-5 (age: 11.0 $\pm$ 0.3 years-old; body mass: 35.3 $\pm$ 7.3 kg; height: 1.41 $\pm$ 0.1 m) and twelve (7 boys and 5 girls) in G-9 (age: 15.0 $\pm$ 0.7 years-old; body mass: 56.7 $\pm$ 11.2 kg; height: 1.63 $\pm$ 0.1 m). All participants and legal guardians were informed of potential benefits and experimental risks prior to the study, and after acceptance, signed the informed consent. The experimental procedures were conducted according with the International Charter for Ethical Research Involving Children and the Declaration of Helsinki. The study was also approved by the local ethics board (UBI/FCSH/DCD/D974 registration).

2.2 Design and procedures

A cross-sectional research design was selected to compare two scholar backpacks in two human locomotion types (i.e., walking and running). Participants attended one single session and they were asked to perform on a wood platform (length: 330 cm; width: 62 cm; high: 6 cm). A force plate (MuscleLab, Ergotest Innovation, Porsgrunn, Norway) 80 cm long, 62 cm wide, and 6 cm high was embedded in the middle of the wood platform. The software Ergotest MuscleLab v8.0 (MuscleLab, Ergotest Innovation, Porsgrunn, Norway) was used to collect and export data from the force platform. All participants were requested to perform the tests wearing their usual daily clothes and sport shoes.

For familiarization purposes, at the beginning of the session, participants were asked to walk, run, and jump on the force platform to achieve their gait pattern without constraints derived from being on a different surface. An individual starting point was set by each participant to ensure movement without adjustments while rising the force platform with the dominant foot (i.e., right foot). All the preparation tasks were performed with and without the traditional and modified backpack. A commercial backpack model was used for the analysis (Padded, 24l, Eastpak, MA, USA) and the backpack was modified by introducing elastics in the strap shoulders (Fig. 1). The sling loops where the elastics were attached were stitched to the strap and placed at 3.5 cm and 14.5 cm from the top of the shoulder strap. This position allowed the elastics to extend from 7 to 8 cm. The elastics were 7 cm long (interior), plus 3.5 cm added for the attachment, 0.5 cm wide and with a thickness of 0.5 cm. The same backpack was used in all trials and it was possible to remove the elastics.

Fig. 1. The modified tested backpack prototype.

The weight carried in the backpack was the average load usually carried by participants according to the school year, as reported elsewhere [4]. The backpack was loaded with 5 kg of books by G-5 children and 4.5 kg by G-9. It was placed over both shoulders and individually adjusted. The adjustment backpack straps were loosened, and the participants were asked to adjust them as they usually do with their backpacks.

In order to avoid the effect of learning or fatigue, the order of task performance was totally randomized using the randbetween function on Microsoft Excel, for each subject. A 5-repetition trial was conducted for each task and all five repetitions were considered for analysis. Each session was conducted with three participants and the resting time between tasks was the necessary time for the other two participants to complete their tasks. Feedback was not provided to participants during the recording trials.

2.3 Data analysis

Microsoft Excel (Microsoft Office 365 ProPlus, Microssoft 365, NM, USA) was used to randomize the performance order conditions and to organize data exported from MuscleLab. The analysed variables were related to the time of support (total or between phases of support) and vertical forces: absolute maximum (MaxAbsl), peak values of each phase of support (Fz1, Fz2, Fz3), integral of forces (or impulse), and loading rate (LoadRate). The force variables magnitudes were also calculated according to the subjects' body weight (BW). The force-time curves were obtained during data colletion [34].

The Shapiro-Wilk test was used to confirm the normality of distribution. Statistical procedures were performed using Statistical Package for the Social Sciences (SPSS v.20, IBM, NY, USA). Descriptive statistics (mean and standard deviation) were reported. T-Test for paired samples was conducted to compare the traditional and the modified backpack. For all tests, the level of statistical significance was set at $p \leq 0.05$. Additionally, the effect size of the differences verified on T-Tests was calculated based on Cohen's d method, using the formula for paired samples proposed by the GPower project. As originally proposed by Cohen [35], the interpretation of the effect sizes was considered as small when $d = 0.2$, medium when $d = 0.5$, and large when $d = 0.8$. The differences between means (Δ) were also analysed for this study.

3. Results

The time and force variables (mean, standard deviations, significance, and effect sizes) for the traditional and modified backpack during the walking condition are presented in Table 1. The application of the elastics on the backpack straps did not change the total stance time and had a small influence on the time parameters for the total sample. However, a significant difference with medium effect was observed in the time variable from Fz2 to Fz3 (s) on the G-9 group (Δ = –0.008; $p = 0.03$; $d = 0.29$). The variables significantly affected in the force variables in the G-9 group were the First peak-Fz1 (N) (Δ = 13.61; $p = 0.039$; $d = 0.27$); Fz2 (N) (Δ = –13.09; $p = 0.039$; $d = 0.27$); Fz2 (N·BW^{-1}) (Δ = –0.02; $p = 0.028$; $d = 0.29$); Total integral (N.s) (Δ = –6.12; $p = 0.037$; $d = 0.27$); Diff. max-min (Δ = 23.05; $p = 0.048$; $d = 0.26$); Integral from Fz2 to Fz3 (Δ = –4.69; $p = 0.028$; $d = 0.29$); Integral after Fz3 (Δ = –2.92; $p = 0.009$; $d = 0.35$). Moreover, the total sample presented significant differences for Integral after Fz3 between the traditional and the modified backpack (Δ = –2.17; $p = 0.005$; $d = 0.28$). Regarding the running condition (Table 2), time variables were not significantly different between the traditional and the modified backpack. Furthermore, force magnitudes did not vary significantly, except for: First peak-Fz1 (kN); First peak-Fz1 (N·BW^{-1}); Integral to first peak (N.s); and Integral to second peak (N.s).

Regarding the comparison between males and females, Table 3 presents the differences between the modified backpacks for boys and girls when walking. The Table 4 presents the comparison when running. For the walking condition, only significant differences were observed fot t to Fz1 (s) for boys (Δ = –0.008; $p = 0.034$; $d = 0.34$) and girls (Δ = 0.005; $p = 0.041$; $d = 0.25$). The load rate presented significant differences for boys (Δ = 0.31; $p = 0.014$; $d = 0.38$) as for Integral after Fz3 (Δ = –3.21; $p = 0.021$; $d = 0.44$), but not for girls.

In Table 4, it is possible to find significant differences for running. The elastics affected the girls' Time between R1 and PA (s) when running (Δ = 0.01; $p = 0.037$; $d = 0.31$), but not the boys'. However, no significant differences were observed in force variables for girls. Otherwise, boys presented significant differences, reducing the force levels in most force variables.

4. Discussion

The current study aimed to investigate whether the introduction of elastic material on backpack straps can be a solution to decrease the magnitude of vertical GRF peaks and loading rate. It was hypothesized that vertical GRF would be lower with elastics in the schoolbag shoulder straps compared to the traditional one without elastics, and that walking would present a lower GRF compared to running. This hypothesis was assumed based on the concept that the elastics can cause an absorption effect, reducing the GRF. Thus, including elastics in the shoulder straps may lead to lower GRF and allow the design of the backpack to be maintained according to children's individual preferences. The main results of this study were that the time and force variables were higher in the traditional school backpack compared to the adapted one when running. However, significant differences were only found in the G-9 group when walking. It was observed that the modification on the backpack induced changes in the GRF magnitudes. The most important finding was probably the decrease in the loading rate and force peaks on some tested conditions.

The purpose of a modified backpack came from the need to reduce the GRF caused by the backpack load [4]. By adapting the backpack it should be possible to achieve biomechanical advantages. These changes should be discrete so that children still find the backpack appealing

Table 1. Time and force variables (mean ± standard deviations) for walking with the traditional backpack and with the modified backpack.

Walking	All students				G-5				G-9			
Time (t) variables	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*
Total stance t (s)	0.649 ± 0.054	0.648 ± 0.046	0.773		0.629 ± 0.050	0.620 ± 0.057	0.174		0.662 ± 0.038	0.670 ± 0.041	0.174	
t to Fz1 (s)	0.141 ± 0.015	0.141 ± 0.018	0.812		0.136 ± 0.017	0.133 ± 0.018	0.507		0.144 ± 0.014	0.147 ± 0.015	0.220	
t from Fz1 to Fz2 (s)	0.167 ± 0.021	0.166 ± 0.026	0.865		0.165 ± 0.025	0.168 ± 0.031	0.500		0.168 ± 0.017	0.165 ± 0.020	0.302	
t from Fz2 to Fz3 (s)	0.181 ± 0.035	0.181 ± 0.03	0.909		0.178 ± 0.045	0.167 ± 0.031	0.076		0.183 ± 0.025	0.191 ± 0.024	0.030	0.29
t after Fz3 (s)	0.159 ± 0.020	0.161 ± 0.024	0.427		0.150 ± 0.019	0.152 ± 0.027	0.665		0.166 ± 0.019	0.168 ± 0.019	0.508	
t between peaks (s)	0.348 ± 0.020	0.347 ± 0.024	0.783		0.343 ± 0.037	0.336 ± 0.034	0.135		0.351 ± 0.023	0.355 ± 0.022	0.285	
Force variables												
First peak-Fz1 (N)	656.77 ± 191.67	650.24 ± 176.25	0.226		507.98 ± 130.27	510.87 ± 95.86	0.749		768.37 ± 150.18	754.76 ± 148.26	0.039	0.27
First peak-Fz1 (N·BW^{-1})	1.42 ± 0.15	1.42 ± 0.17	0.827		1.46 ± 0.14	1.48 ± 0.15	0.251		1.39 ± 0.16	1.37 ± 0.17	0.058	
Fz2 (N)	330.57 ± 102.44	339 ± 107.33	0.089		248.56 ± 44.67	250.8 ± 69.6	0.779		392.07 ± 89.62	405.16 ± 79.44	0.039	0.27
Fz2 (N·BW^{-1})	0.72 ± 0.11	0.73 ± 0.1	0.359		0.73 ± 0.13	0.72 ± 0.12	0.638		0.71 ± 0.09	0.73 ± 0.07	0.028	0.29
Second peak-Fz3 (N)	611.26 ± 162.2	610.85 ± 156.57	0.916		481.65 ± 94.61	483.86 ± 81.32	0.672		708.46 ± 131.45	706.1 ± 129.43	0.672	
Second peak-Fz3 (N·BW^{-1})	1.33 ± 0.11	1.34 ± 0.13	0.607		1.40 ± 0.1	1.41 ± 0.12	0.33		1.28 ± 0.09	1.28 ± 0.11	0.796	
Max Absl (N)	665.78 ± 185.64	658.11 ± 175.83	0.118		520.92 ± 125.04	516.32 ± 93.13	0.575		774.42 ± 145.19	764.45 ± 145.58	0.102	
Max Relative (N·BW^{-1})	1.45 ± 0.17	1.44 ± 0.17	0.364		1.50 ± 0.11	1.50 ± 0.13	0.917		1.42 ± 0.19	1.40 ± 0.19	0.117	
Total integral (N.s)	266.09 ± 80.95	268.94 ± 83.22	0.142		201.06 ± 43.95	199.54 ± 50.04	0.499		314.86 ± 66.83	320.98 ± 62.57	0.037	0.27
LoadRate (kN·s^{-1})	4.69 ± 1.32	4.63 ± 1.18	0.492		3.79 ± 1.12	3.89 ± 0.88	0.537		5.36 ± 1.05	5.18 ± 1.08	0.081	
Diff. max-min	335.21 ± 141.72	319.11 ± 124.63	0.085		272.36 ± 124.55	265.52 ± 89.16	0.658		382.35 ± 136.24	359.3 ± 132.74	0.048	0.26
Integral to P1	58.64 ± 19.25	58.37 ± 19.54	0.812		43.79 ± 12.1	43.17 ± 11.27	0.632		69.78 ± 15.8	69.77 ± 16.44	0.996	
Integral from Fz1 to Fz2	76.79 ± 23.86	76.34 ± 23.35	0.716		58.22 ± 14.62	59.17 ± 15.84	0.597		90.71 ± 19.6	89.23 ± 19.5	0.377	
Integral from Fz2 to Fz3	84.49 ± 30.58	85.88 ± 31.43	0.384		64.17 ± 21.33	61.16 ± 20.46	0.201		99.74 ± 27.52	104.42 ± 24.78	0.028	0.29
Integral after Fz3	46.17 ± 15.35	48.34 ± 16.78	0.005	0.28	34.88 ± 8.8	36.04 ± 12.14	0.267		54.64 ± 13.69	57.56 ± 13.59	0.009	0.35

Fz1, first vertical force peak; Fz2, vertical force relative minimum; Fz3, second vertical force peak.

Table 2. Time and force variables (mean ± standard deviations) for running with the traditional backpack and with the modified backpack.

Running	All students				G-5				G-9			
	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*
Time variables												
Total stance time (s)	0.312 ± 0.030	0.310 ± 0.029	0.632		0.301 ± 0.027	0.297 ± 0.025	0.459		0.320 ± 0.029	0.320 ± 0.028	0.913	
Time to R1(s)	0.038 ± 0.010	0.039 ± 0.010	0.150		0.038 ± 0.010	0.038 ± 0.009	1.000		0.037 ± 0.010	0.040 ± 0.010	0.075	
Time to PA (s)	0.132 ± 0.017	0.127 ± 0.031	0.153		0.126 ± 0.018	0.123 ± 0.023	0.456		0.135 ± 0.016	0.130 ± 0.036	0.226	
Time between R1 and PA (s)	0.094 ± 0.017	0.090 ± 0.024	0.098		0.089 ± 0.016	0.087 ± 0.018	0.609		0.098 ± 0.017	0.093 ± 0.028	0.096	
Force variables												
First peak-Fz1 (kN)	0.626 ± 0.228	0.615 ± 0.201	0.288		0.488 ± 0.156	0.476 ± 0.129	0.458		0.729 ± 0.220	0.718 ± 0.183	0.449	
First peak-Fz1 ($N{\cdot}BW^{-1}$)	1.38 ± 0.31	1.33 ± 0.24	0.090		1.41 ± 0.35	1.37 ± 0.21	0.388		1.35 ± 0.28	1.3 ± 0.26	0.113	
Second peak-Fz2 (kN)	1.16 ± 0.37	1.15 ± 0.37	0.022	0.23	0.840 ± 0.170	0.821 ± 0.151	0.040	0.32	1.41 ± 0.29	1.39 ± 0.29	0.161	
Second peak-Fz2 ($N{\cdot}BW^{-1}$)	2.55 ± 0.39	2.46 ± 0.26	0.002	0.30	2.43 ± 0.18	2.38 ± 0.23	0.073		2.64 ± 0.48	2.51 ± 0.27	0.009	0.35
Max absolute (kN)	1.16 ± 0.37	1.15 ± 0.37	0.021	0.23	0.840 ± 0.170	0.821 ± 0.151	0.036	0.32	1.41 ± 0.29	1.39 ± 0.29	0.161	
Max relative ($N{\cdot}BW^{-1}$)	2.5 ± 0.38	2.46 ± 0.39	0.018	0.23	2.38 ± 0.17	2.34 ± 0.23	0.063		2.59 ± 0.47	2.56 ± 0.46	0.130	
LoadRate to first peak ($kN{\cdot}s^{-1}$)	18.05 ± 7.98	16.80 ± 7.15	0.035	0.21	14.38 ± 7.46	13.30 ± 5.23	0.164		20.78 ± 7.28	19.41 ± 7.31	0.113	
LoadRate second peak ($kN{\cdot}s^{-1}$)	8.96 ± 3.06	8.63 ± 2.79	0.017	0.24	6.78 ± 1.69	6.57 ± 1.32	0.288		10.59 ± 2.84	10.18 ± 2.60	0.028	0.29
Integral total (N.s)	183.04 ± 59.9	180.35 ± 58.88	0.007	0.27	130.8 ± 30.17	127.57 ± 26.7	0.033	0.33	222.22 ± 44.77	219.93 ± 43.15	0.092	
Integral to first peak (N.s)	8.95 ± 4.3	9.00 ± 3.88	0.892		7.59 ± 3.31	7.56 ± 3.36	0.965		9.96 ± 4.68	10.06 ± 3.92	0.847	
Integral to second peak (N.s)	88.73 ± 28.64	88.51 ± 29.06	0.811		63.04 ± 16.98	62.48 ± 16.02	0.635		108 ± 18.72	108.02 ± 19.84	0.984	
Integral after second peak (N.s)	94.31 ± 33.02	91.84 ± 31.67	0.008	0.26	67.76 ± 16.05	65.08 ± 12.54	0.038	0.32	114.22 ± 28.09	111.91 ± 26.37	0.084	

after the applied modifications. It is counterproductive to achieve the most biomechanical beneficial backpack if children won't make use of it. The introduction of the elastic on the shoulder straps [29] did not significantly change the backpack design or alter the total stance time when compared to the non-modified backpack.

When walking, only G-9 experimented significant differences between the two conditions. When using the modified backpack, G-9 prolonged the phase between Fz2 (vertical force relative minimum) and Fz3 (second vertical force peak). This may be due to the moving up from the center of gravity, originated by the propulsion force produced in this phase, forcing the elastic to elongate. This resulted in the production of more energy in this phase, which is confirmed by the increased integral data. The integral data, impulse, or the "amount of force" produced was higher in the second half of the stance, probably to restore the elastic energy absorbed in the first half. The great advantages presented by using the modified backpack were the decrease in the first vertical force peak and the decrease of the loading rate, which were probably due to the energy absorption induced by the elastics. The increase of the Fz2 (minimum relative) was also a reflex of the elastics action, dissipating energy from the first peak to the following moments. This may be seen as a small phase delay of the load due to the straps, similar to another study with a suspended-load backpack [36]; however, there's a lack of research in this field. A previous study presented the same results for the walking condition and the integral force was lower compared to running [34]. This may speculate that the straps will allow the decrease of the integral force for each locomotion type. Moreover, the same study [34] presented similar results between loaded and unloaded bags, which probably means the straps will produce a reduction in the load mechanical effects.

Thus, for the G-9, when walking, the action of the elastics allowed a decrease in the force peak, "distributing" the force difference over the next stance moments. The G-5 did not present differences between the two backpacks, probably because the carried load was so high that it stretched the elastics completely, leaving no room for them to work. It is possible to compare this effect between loaded and unloaded bags [34]. However, the magnitude of the effects was different in the present study with straps compared with different loads [4]. When running, there were no changes in the time variables, but similarly to walking, the force variables suffered modifications. Again, with the use of the modified backpack, the force peak value decreased as well as the loading rate. Probably, the elastic absorbed a part of the energy generated by the vertical brake of the stance, dissipating it along the time and lowering the maximum level of the vertical force. These results are largely expected based on the literature, in which peak force values are higher in running conditions [34,37]. As for running, the total generated impulse decreased with the modified backpack. A possible explanation for this could be the reduced rebound of the backpack on the shoulders, promoted by the action of the elastics. With a reduced rebound, the negative vertical acceleration of the backpack would also be reduced, decreasing the need to cause impulse to neutralize it [36].

The G-5 experienced differences between the two backpacks when running, contrary to walking. Although the load carried was the same on both conditions, when running the backpack presented greater rebounds, which could help to explain the change, as they probably promote moments when the elastics could shorten, and then be able to stretch again, absorbing energy [37]. These findings, specially the decrease on the vertical force peaks with the use of the modified backpack, are in agreement with the theoretical model by Ren *et al.* [33], in which it is suggested that a backpack suspension model with a lower stiffness may offer biomechanical advantages, namely the decrease on the peak values of the GRF. However, it is important to note that the G-5 typically carries higher backpack loads [4].

A comparison between modified and traditional backpacks was carried out for boys and girls. For walking, few differences were observed in the present study. However, for running, the boys presented higher differences regarding force variables. In the present study, boys typically presented higher ground reaction forces. The literature supports these findings, confirming that the locomotion technique between boys and girls explains the differences because boys tend to apply higher force load when running [38]. However, significant differences were only observed in the running condition when comparing traditional to modified backpacks.

The decrease on the vertical GRF and loading rate may represent important advantages in favour of the introduction of elastic material on the shoulder straps of school backpacks. This study can probably encourage a deep understanding of how these benefits can be controlled and maximized. The different modifications observed between G-5 and G-9 could mean that the elastic stiffness needs to be adjusted concerning the carried load, children's body weight, or the relation between both. After determining this, it could be applied as a combination of elastics that children would apply to their backpack depending on the load they have to carry, their body weight, or a combination of both. If there is the need to combine different elastics with different characteristics, the elastics could be differentiated by the use of different colors. The researchers of the current study believe this is a practical and commercially viable idea.

The differences in the use of the two backpacks in some variables were significant when considering all the elements of the sample; however, this didn't happen when analyzing the groups separately. That occurred mainly when running and may be evidence that the sample size should be bigger. The backpack was modified introducing the elastics on the shoulder straps but without discontinuing the straps. The effect could be different if the straps were cut and at-

Table 3. Time and force variables (mean ± standard deviations) for boys and girls while walking with the traditional backpack and with the modified backpack.

Walking	Girls				Boys			
	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*
Time (t) variables								
Total stance t (s)	0.647 ± 0.04	0.655 ± 0.06	0.34		0.648 ± 0.05	0.645 ± 0.05	0.474	
t to Fz1 (s)	0.137 ± 0.02	0.145 ± 0.02	0.010	0.34	0.143 ± 0.01	0.138 ± 0.02	0.041	0.25
t from Fz1 to Fz2 (s)	0.164 ± 0.02	0.161 ± 0.03	0.562		0.169 ± 0.02	0.17 ± 0.02	0.740	
t from Fz2 to Fz3 (s)	0.185 ± 0.04	0.183 ± 0.03	0.820		0.178 ± 0.03	0.179 ± 0.03	0.932	
t after Fz3 (s)	0.161 ± 0.02	0.166 ± 0.03	0.285		0.158 ± 0.02	0.158 ± 0.02	0.944	
t between peaks (s)	0.349 ± 0.03	0.345 ± 0.03	0.442		0.347 ± 0.03	0.349 ± 0.03	0.696	
Force variables								
First peak-Fz1 (N)	610.87 ± 150.69	601.87 ± 132.04	0.222		691.19 ± 212.16	686.52 ± 196.56	0.545	
First peak-Fz1 ($N{\cdot}BW^{-1}$)	1.37 ± 0.12	1.36 ± 0.14	0.544		1.46 ± 0.17	1.46 ± 0.17	0.875	
Fz2 (N)	330.15 ± 90.23	346.07 ± 104.27	0.041		330.88 ± 111.46	333.71 ± 110.15	0.660	
Fz2 ($N{\cdot}BW^{-1}$)	0.74 ± 0.07	0.76 ± 0.09	0.103		0.71 ± 0.12	0.7 ± 0.09	0.847	
Second peak-Fz3 (N)	591.92 ± 127.69	601.8 ± 137.38	0.091		625.76 ± 183.61	617.64 ± 170.37	0.112	
Second peak-Fz3 ($N{\cdot}BW^{-1}$)	1.34 ± 0.11	1.36 ± 0.13	0.106		1.33 ± 0.11	1.32 ± 0.13	0.467	
Max Absl (N)	621.46 ± 145.39	616.68 ± 136.56	0.477		699.02 ± 205.82	689.18 ± 195.7	0.162	
Max Relative ($N{\cdot}BW^{-1}$)	1.40 ± 0.1	1.39 ± 0.13	0.750		1.49 ± 0.19	1.48 ± 0.19	0.382	
Total integral (N.s)	257.13 ± 65.98	262.91 ± 74.2	0.081		272.81 ± 90.54	273.45 ± 89.75	0.782	
LoadRate ($kN{\cdot}s^{-1}$)	4.51 ± 1.22	4.20 ± 1.03	0.014	0.38	4.83 ± 1.40	4.96 ± 1.20	0.280	
Diff. max-min	291.31 ± 88.05	270.62 ± 81.46	0.135		368.14 ± 164.47	355.48 ± 138.9	0.321	
Integral to P1	54.58 ± 14.16	55.7 ± 15.14	0.364		61.69 ± 21.94	60.37 ± 22.2	0.227	
Integral from Fz1 to Fz2	72.76 ± 22.26	71.6 ± 21.31	0.579		79.81 ± 24.74	79.9 ± 24.34	0.950	
Integral from Fz2 to Fz3	83.54 ± 26	86.14 ± 29.1	0.325		85.21 ± 33.81	85.68 ± 33.32	0.812	
Integral after Fz3	46.26 ± 12.99	49.47 ± 16.44	0.021	0.44	46.1 ± 17.02	47.49 ± 17.12	0.117	

Table 4. Time and force variables (mean ± standard deviations) for boys and girls while running with the traditional backpack and with the modified backpack.

Running	Girls				Boys			
	Traditional Backpack	Modified Backpack	*p*	*d*	Traditional Backpack	Modified Backpack	*p*	*d*
Time variables								
Total stance time (s)	0.313 ± 0.03	0.313 ± 0.03	0.956		0.311 ± 0.03	0.309 ± 0.03	0.494	
Time to R1(s)	0.03 ± 0.01	0.04 ± 0.01	0.452		0.04 ± 0.01	0.04 ± 0.01	0.210	
Time to PA (s)	0.13 ± 0.02	0.13 ± 0.03	0.107		0.13 ± 0.02	0.13 ± 0.03	0.582	
Time between R1 and PA (s)	0.10 ± 0.02	0.09 ± 0.02	0.037	0.31	0.09 ± 0.01	0.09 ± 0.02	0.757	
Force variables								
First peak-Fz1 (kN)	0.59 ± 0.19	0.58 ± 0.17	0.516		0.66 ± 248.2	0.64 ± 0.22	0.406	
First peak-Fz1 ($N{\cdot}BW^{-1}$)	1.34 ± 0.36	1.31 ± 0.26	0.548		1.41 ± 0.27	1.35 ± 0.22	0.084	
Second peak-Fz2 (kN)	1.08 ± 0.31	1.08 ± 0.31	0.814		1.22 ± 0.4.1	1.19 ± 0.41	0.008	0.35
Second peak-Fz2 ($N{\cdot}BW^{-1}$)	2.41 ± 0.18	2.4 ± 0.18	0.623		2.55 ± 0.27	2.50 ± 0.3	0.014	0.33
Max absolute (kN)	1.08 ± 0.31	1.08 ± 0.31	0.784		1.22 ± 0.41	1.19 ± 0.41	0.008	0.35
Max relative ($N{\cdot}BW^{-1}$)	2.41 ± 0.18	2.40 ± 0.18	0.550		2.55 ± 0.27	2.50 ± 0.3	0.014	0.33
LoadRate to first peak ($kN{\cdot}s^{-1}$)	19.20 ± 9.17	17.29 ± 7.48	0.055		17.19 ± 6.92	16.44 ± 6.94	0.303	
LoadRate second peak ($kN{\cdot}s^{-1}$)	8.27 ± 2.68	8.21 ± 2.25	0.750		9.47 ± 3.24	8.95 ± 3.118	0.004	0.38
Integral total (N.s)	174.384 ± 50.04	173.238 ± 50.3	0.370		189.537 ± 66.01	185.68 ± 64.48	0.009	0.35
Integral to first peak (N.s)	7.56 ± 3.2	8.44 ± 3.23	0.128		9.98 ± 4.73	9.41 ± 4.28	0.221	
Integral to second peak (N.s)	86.06 ± 25.6	85.1 ± 26.89	0.515		90.74 ± 30.79	91.06 ± 30.56	0.792	
Integral after second peak (N.s)	88.33 ± 26.56	88.13 ± 26.09	0.893		98.8 ± 36.71	94.62 ± 35.24	0.001	0.46

tached exclusively by the elastics, promoting a bigger range of motion for the elastics. This idea is probably worth exploring. In the search for an ideal elastic stiffness, there are many levels of the variables to be tested, such as elastics with different dimensions, characteristics, and resistance, combined with different loads and children's BW. There is still a very wide field to be analyzed, such as the effects of elastics on the shoulder straps when jumping or rotating. Nevertheless, this should be studied first in a laboratory with a mechanical "subject", due to the variety of conditions to be tested, and only then, in a second phase, with children, to clarify the results.

5. Conclusions

The introduction of elastic on the shoulder straps of a school backpack modified the GRF parameters, when walking and when running. The main goal of reducing the vertical peak force levels and loading rate was achieved but not in every condition/age group. More research should be done to define the parameters to be controlled in order to maximize that effect.

Abbreviations

GFR, Ground Reaction Force; G-5, 5th grade; G-9, 9th grade.

Author contributions

Conceptualization—MCM, MI, DAM; Data curation—JB, CCS, PF; Formal analysis—JB, PF, HPN; Funding acquisition—DAM; Investigation—JB, CCS, HPN; Methodology—MCM, DAM, MI; Project administration—MCM, MI; Resources—DAM, HPN; Software—JB, CCS; Supervision—MCM, DAM, MI; Validation—PF, HPN; Visualization—JB, CCS, PF, HPN; Roles/Writing - original draft—JB, CCS, PF, HPN; Writing - review & editing—MCM, DAM, MI.

Ethics approval and consent to participate

The experimental procedures were conducted according with the International Charter for Ethical Research Involving Children and the Declaration of Helsinki, The study was also approved by the local ethics board (UBI/FCSH/DCD/D974 registration).

Acknowledgment

Thanks to all the peer reviewers for their opinions and suggestions.

Funding

This work is supported by national funding through the Portuguese Foundation for Science and Technology, I.P., under the project UIDB/04045/2020.

Conflict of interest

The authors declare no conflict of interest. PF, HPN and DAM are serving as one of the Guest editors and DAM is serving as one of the Editorial Board members of this journal. We declare that PF, HPN and DAM had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to AT.

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