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Does schoolbag carriage equally affect obese/overweight and healthy-weight children?

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ABSTRACT

Discrepancies exist in backpack load recommendations for obese/overweight children, and the recommendations do not consider school trolleys. This study analysed obese/overweight and healthy-weight students' perceived load and fatigue when carrying schoolbags and their gait kinematics and rate of perceived exertion (RPE) when carrying backpacks or pulling school trolleys with different loads. Twelve obese/overweight and 36 healthy-weight students were asked about their perceived load and fatigue in carrying their schoolbags to school. Then, a kinematic gait analysis was completed in students walking unloaded or transporting 10%, 15% or 20% of their bodyweight (BW) in a backpack or trolley. RPE was recorded after each condition.

The average hip rotation and knee adduction angles differed between body mass index (BMI) groups. The healthy-weight group reported higher RPEs than the overweight/obese group when pulling a trolley with 10–15% BW.

In conclusion, both BMI groups responded similarly to load and schoolbag type.

1. Introduction

In 2016, over 340 million individuals, including 18% of children and adolescents aged 5–19 years, were overweight or obese, defined as having a body mass index (BMI) greater than 1 standard deviation above the World Health Organization growth reference median for overweight or 2 standard deviations above the median for obesity (World Health Organization (WHO), 2018). The recommended maximum backpack loads are between 10 and 15% of a child's body weight (BW) (American Physical Therapy Association (APTA), 2016; Asociación Española de Pediatria, 2014), although previous studies have posited that since overweight children already carry additional intrinsic weight, their maximum backpack load should be less than that of their healthy counterparts (Adeyemi et al., 2015, 2017).

In this context, a study by Adeyemi et al. (2017) performed structural equation modelling based on descriptive measures of backpack-related back pain, anthropometry, and posture variables (back inclination and neck inclination). In that study, it was concluded that obese children should be limited to a maximum backpack weight of 10% BW, as opposed to the limit of 15% BW for healthy-weight children. In another study by Adeyemi et al. (2015), it was proposed that obese schoolchildren should carry less weight than healthy-weight children due to the significant effect of BMI on the muscle activity of the left erector spinae; they found that the fatigue caused by carrying different loads (5%, 10% and 15% BW) in a backpack for 5 min increased with BMI.

Although specific backpack weight recommendations for obese/overweight children have been proposed, the postural adaptations these children use when walking while carrying different schoolbag loads have not been analysed. A previous study concluded that pulling between 10% and 20% BW in a school trolley allowed the maintenance of walking kinematics similar to those of unloaded walking, while carrying 10% BW or more in a backpack did not (Orantes-Gonzalez et al., 2019). A school trolley enables children to transport heavier loads while walking on level ground with smaller kinematic adaptations in the ankle, hip, pelvis and thorax than when using a traditional backpack (Orantes-Gonzalez et al., 2017).

In an analysis of the spatiotemporal and kinematic differences between obese/overweight and healthy-weight groups when not carrying any load, the obese group walked with a shorter single support phase than the healthy-weight group, although the differences in cadence, stride length, stance phase, and double stance phase were non-

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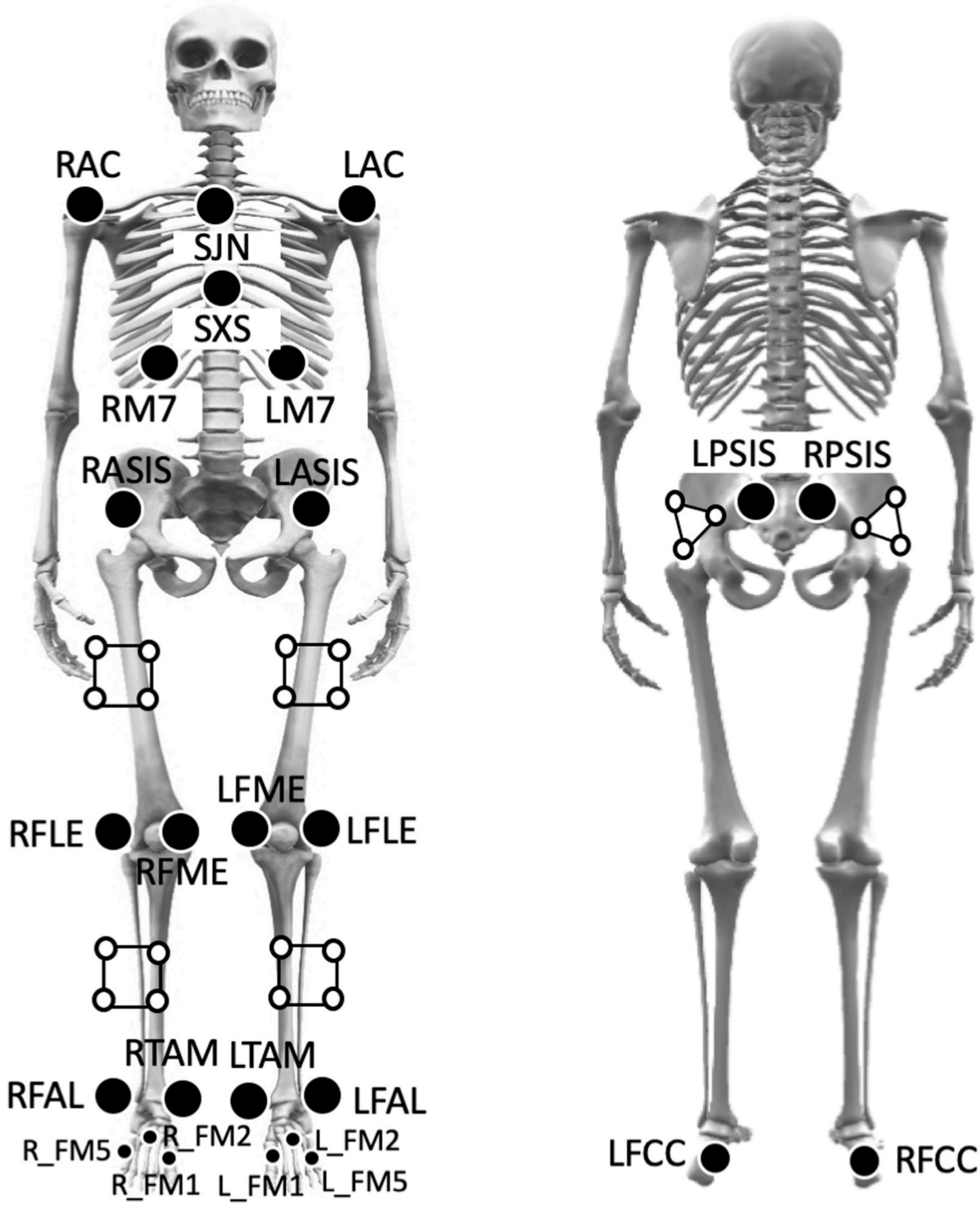

Fig. 1. Marker locations for the gait kinematic analysis. Thorax: right and left acromioclavicular markers (RAC, LAC), jugular notch of the sternum (SJN), xiphisternum (SXS) and costal cartilage of the 7th ribs (RM7, LM7). Pelvis: right and left anterior superior iliac spine (RASIS, LASIS) and posterior superior iliac spine (RPSIS, LPSIS). Thighs: lateral and medial epicondyles of the right and left femurs (RFLE, LFLE; RFME, LFME). Shanks: apices of the lateral malleoli of the right and left fibulae (RFAL, LFAL) and apices of the medial malleoli of the right and left tibiae (RTAM, LTAM). Foot: right and left posterior calcaneal surfaces (RFCC, LFCC), heads of 1st metatarsals (RFM1, LFM1), bases of 2nd metatarsals (RFM2, LFM2) and heads of 5th metatarsals (RFM5, LFM5). The markers aligned in the pelvis, thighs and shanks represented clusters of markers.

significant (Nantel et al., 2006). A further study reported that increased body fat reduced early stance knee flexion angles and increased pelvic obliquity (Lerner et al., 2014). In contrast to those results, other studies did not report differences between overweight and healthy-weight children in terms of kinematic parameters (Shultz et al., 2009), postural control (Pau et al., 2012) or lower extremity muscle activity during gait (Blakemore et al., 2013).

With respect to the influence of BMI on schoolbag-related musculoskeletal pain and psychosocial factors, the results are controversial. While some studies did not find significant evidence related to an influence of BMI on the rating of pain/discomfort after carrying a backpack (Adeyemi et al., 2015; Dockrell et al., 2015; Aprile et al., 2016), other studies suggested that BMI could be a factor in schoolbag-related musculoskeletal pain/discomfort (Lindstrom-Hazel, 2009; Dianat et al., 2013). In terms of the rate of perceived exertion (RPE) and BMI, no previous studies have examined the effect of BMI on RPE values while carrying a backpack. In other tasks, such as walking on a treadmill, Marinov et al. (2002) reported higher RPE scores in obese children than in healthy-weight children, while other previous studies obtained lower RPE values in overweight children than in healthy-weight children during submaximal cycling (Laurent et al., 2019).

Therefore, given the discrepancy of the previous results and the fact that no previous studies have analysed the effect of different modes of schoolbag carriage (e.g., pulling a school trolley) on kinematics or RPE in overweight/obese and healthy-weight children, we performed this study with the aim of analysing the postural and gait adaptations and RPE of obese/overweight and healthy-weight children when carrying a backpack or pulling a school trolley with different loads. An additional aim was to analyse the perceived load and fatigue when the children carried their own schoolbags to school.

2. Methods

2.1. Participants

Forty-eight students aged 6–12 years participated in this study. The height and weight of each child were measured using a scale and measuring rod (SECA769, Hamburg, Germany). The BMI of each child was calculated as weight (in kilograms) divided by height squared (in metres). Then, it was classified following the international age-based classification for girls and boys from 2 to 20 years (Cole et al., 2000). Children were classified as healthy if their BMI was between the 5th and 85th percentiles; overweight if their BMI was between the 85th and 95th percentiles; and obese if their BMI was above the 95th percentile. All of the students were volunteers, and their parents completed informed consent forms. Children were excluded if they had experienced recent orthopaedic trauma, neurologic problems, or were unable to carry a backpack or a trolley. The ethics committee of the university approved this study.

2.2. Procedures

Before data collection, the parents of each participant were asked about the participant's previous history of motor or neurological disorders. Then, each child was asked about the type of schoolbag they took to school and the perceived schoolbag load and fatigue when carrying his or her schoolbag to school. To analyse the perceived load and fatigue that the students experienced when carrying their schoolbags, we asked the participants the following questions based on the questionnaires used in previous studies (Negrini and Carabalona, 2002; Haselgrove et al., 2008): "Do you feel your schoolbag is too heavy?" and "Do you feel tired when carrying your schoolbag?" The answers were categorized as follows: "Yes, always"; "Yes, sometimes"; or "No, never".

Then, to analyse the kinematic adaptation to load and type of schoolbag (trolley vs backpack) in each BMI group, we measured the spatiotemporal gait variables and the kinematics of the lower limb and thorax as children walked at their preferred speed for 1 min under the following experimental conditions: no bag (as the control); carrying a backpack with 10%, 15% and 20% BW; and pulling a trolley with the same loads. At the start of the data collection, each participant walked at least three times along the 15 m walkway without a bag to become familiar with the protocol. Subsequently, the children completed each condition in a random order, with 3 min of rest between conditions.

The different loads were achieved by filling the backpack/school trolley with books of different weights. The backpack was a standard model (American Tourister, Samsonite, UK) and was carried on both shoulders, with the bottom of the backpack level with the waistline. The school trolley (TrainingPixel, Chamoe, Spain) had 4 wheels, although only two wheels were in contact with the ground when it was being pulled. The height of the trolley was 0.89 m from the top of the handle to the bottom part of the trolley. All of the participants pulled the trolley using the dominant hand, and all of them were right-handed.

While children were walking in the different experimental conditions, a 3D motion capture system (Qualisys AB, Göteborg, Sweden) was used to record the trajectory of the calibrated anatomical systems technique (CAST) model markers (Fig. 1) as described in previous studies (Orantes-Gonzalez et al., 2017, 2019). The locations of the reflective markers were collected using nine high-speed infrared cameras recording at 250 Hz. Visual 3D software (C-Motion Inc., Germantown, USA) was used to build a geometric model of 8 segments, which was subsequently used to obtain the gait kinematic curves and spatiotemporal gait parameters.

In each experimental condition, the following spatiotemporal variables were analysed: velocity (m/s); cadence (steps/minute); step length (m); and the swing phase, stance phase, single support phase and double support phase measured and expressed as a % of the gait cycle (GC). The spatiotemporal parameters were calculated as the mean of both legs and normalized to the duration of the walking gait cycle of each subject.

In the kinematic analysis, the flexion/extension, adduction/abduction and internal/external rotation movements of the hip and knee; the tilt, obliquity and rotation of the pelvis; and the flexion/extension, lateral bending and rotation of the thorax were obtained. The pelvic angle was expressed as movement of the pelvis relative to the global coordinate system. The hip angle was defined by the pelvis and femur, the knee angle was determined by the thigh and shank, and the pelvis and thorax segments were determined the thorax angle. From each of those joint angles, the mean and standard deviation (in degrees), averaged for both legs, were obtained and normalized to the duration of the GC for each subject (from 0 to 100% of GC) in each experimental condition.

In addition, after the completion of each trial, RPE data were recorded using the Children's OMNI Scale (Uetter et al., 2002). This scale contains pictures and verbal explanations that correspond to a numerical range from 0 to 10 (0 indicates no fatigue at all, and 10 indicates extreme fatigue) to evaluate perceived effort.

Table 1
Descriptive data on healthy-weight and obese/overweight participants, reported as the mean (standard deviation) and significance level in the between-group comparisons (p). Significant between-group differences are in bold.

	Healthy-weight	Obese/overweight	p value
Age (years)	9.9 (1.9)	10 (1.6)	0.51
Height (m)	1.45 (0.1)	1.44 (0.1)	0.51
Weight (kg)	37.6 (9.7)	45.8 (14.4)	**0.01**
BMI (kg/m2)	17.5 (1.8)	22.6 (3.1)	**<0.001**

BMI: body mass index.

2.3. Statistical analysis

SPSS software v.23 (IBM SPSS, Armonk, NY) was used for the data analysis. Descriptive data were compared between groups using an independent samples *t*-test. The children's perceptions of load and fatigue when they carried their schoolbags were analysed through descriptive statistics (frequency and percentages). The spatiotemporal and kinematic variables were analysed with a three-way mixed ANOVA with BMI as the between-subjects factor and load and schoolbag type as within-subject factors. According to the aims of the study, only the main effect of BMI and the interactions of BMI with load and type of schoolbag were analysed. Tukey's post hoc test was used whenever significant differences were found. The Kolmogorov–Smirnov test was used to test data normality, and Levene's test was used to test the homogeneity of variance. Mauchly's test was used to assess sphericity. Differences in the RPE scores between BMI groups were calculated using independent t-tests. The threshold for statistical significance was set at $p < 0.05$.

3. Results

In the classification of participants by BMI, 3 children were obese, 9 were overweight and 36 were healthy. Overweight and obese children were grouped together for comparisons with healthy-weight children. Descriptive data and between-group comparisons are shown in Table 1.

Table 2
Students' perceived load and fatigue when carrying their own schoolbags (backpacks or school trolleys) to school [percentage (number)] in the healthy and overweight/obese groups.

	Backpack users		Trolley users	
	Healthy	Obese/ overweight	Healthy	Obese/ overweight
Feeling school bag heavy				
Always	23.8% (5)	–	–	16.7% (1)
Sometimes	76.2% (16)	83.3% (5)	93.3% (14)	66.7% (4)
Never	–	3.7% (1)	6.7% (1)	16.7% (1)
Feeling fatigue during carriage				
Always	14.3% (3)	–	6.7% (1)	16.7% (1)
Sometimes	81% (17)	66.7% (4)	53.3% (8)	50% (3)
Never	4.8% (1)	33.3 (2)	40% (6)	33.3 (2)

Table 3
F (p value) for the effects and interactions of load, schoolbag (Sbag) and body mass index (BMI) for the spatiotemporal gait parameters analysed. Significant effects are in bold.

	BMI	Load*BMI	Sbag*BMI	Load*Sbag*BMI
Velocity (m/s)	0.12 (0.73)	0.42 (0.74)	**9.08 (0.004)**	1.35 (0.26)
Cadence (steps/min)	0.04 (0.84)	1.63 (0.18)	1.58 (0.21)	1.63 (0.19)
Step Length (m)	0.11 (0.75)	0.33 (0.80)	4.75 (0.06)	0.95 (0.42)
Stance phase (%GC)	4.11 (0.05)	0.91 (0.42)	0.27 (0.61)	0.04 (0.97)
Swing phase (%GC)	4.31 (0.05)	0.96 (0.42)	0.08 (0.78)	0.17 (0.91)
Double support phase (%GC)	4.03 (0.06)	0.18 (0.88)	1.44 (0.23)	0.88 (0.46)

Fifty percent of the participants in each BMI group carried backpacks to school, while the other 50% used school trolleys.

3.1. Perceived load and fatigue of students carrying their own schoolbags to school

The perceived load and fatigue when children carried their own schoolbags to school are shown in Table 2. Perceived schoolbag weight was not significantly different between BMI groups or between users of different types of schoolbags. A higher proportion of healthy-weight children than obese/overweight children reported fatigue when carrying their own backpacks (Table 2).

3.2. Spatiotemporal parameters

In the comparisons between BMI groups, non-significant differences were found in the spatiotemporal gait parameters analysed (Table 3). The interaction analysis showed significant differences only in the schoolbag × BMI interaction for velocity (Table 3).

The post hoc analysis revealed that healthy-weight children walked faster when pulling the trolley with 10% and 20% BW than when carrying the same loads in the backpack (Fig. 2). In addition, the healthy-weight group had a slower velocity in the backpack load conditions than in the control condition (Fig. 2).

3.3. Kinematic parameters

In the comparisons between BMI groups, differences were found in the internal/external rotation movements of the hip and in the adduction/abduction movements of the knee (Table 4). In the interaction analysis, significant differences were found in the internal/external rotation movements of the hip in the interactions between schoolbag type and BMI as well as for the interaction of load, schoolbag type and BMI (Table 4).

The post hoc comparisons showed differences in the internal/external rotation movements of the hip between BMI groups in the control condition and in the different load conditions (Fig. 3). In addition, in the obese/overweight group, differences were found between the load conditions when carrying the backpack and when pulling the trolley (Fig. 3). Regarding the adduction/abduction movements of the knee, there were significant differences between BMI groups for all the conditions tested (Fig. 3).

3.4. RPE

The healthy-weight group reported higher RPE scores than the overweight/obese group after pulling the school trolley with 10% and 15% BW (Fig. 4).

4. Discussion

Previous studies have recommended reduced backpack weights for obese/overweight students based on their posture in static positions or on mathematical models derived from descriptive data (Adeyemi et al., 2015, 2017); no other type of schoolbag, such as a school trolley, was tested. Therefore, the kinematic adaptations of different BMI groups while walking and their perceptions of fatigue and weight when carrying a backpack or a school trolley remained unclear. To better inform load recommendations, the present study analysed the kinematic adaptations required to carry a backpack and pull a trolley, together with perceived fatigue and equipment weight and RPE, in different BMI groups.

With respect to the psychosocial factors analysed, the different BMI groups' perceptions regarding the weight of their own school backpacks

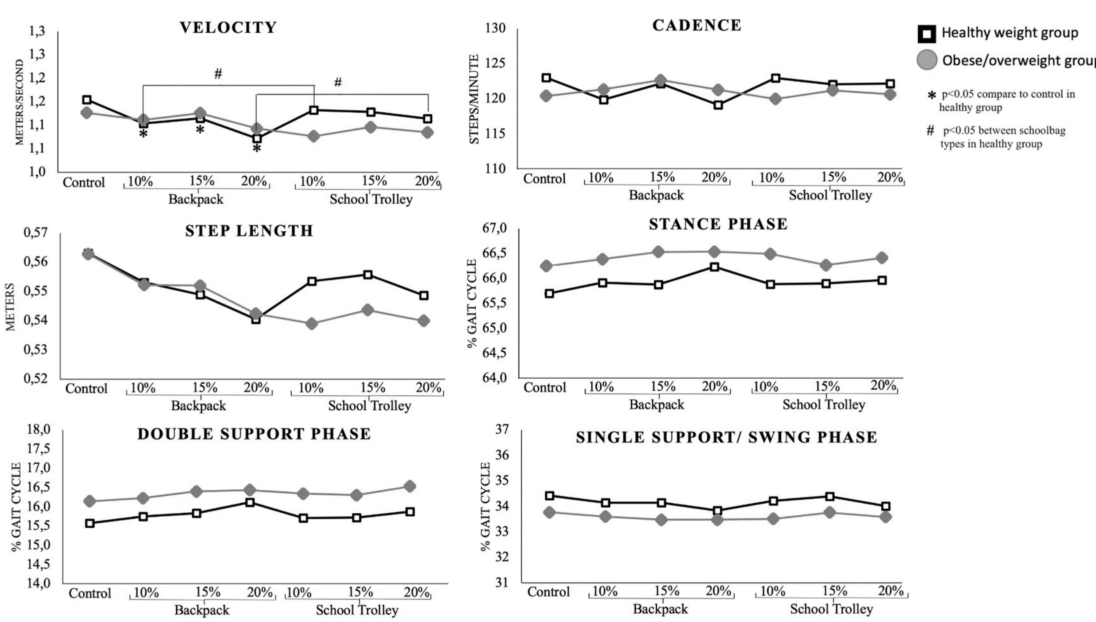

Fig. 2. Spatiotemporal gait parameters of the healthy-weight group (black line) and the obese/overweight group (grey line) for the different experimental conditions. *: p <0.05 compared to the control in the healthy-weight group. #: p<0.05 between schoolbag types in healthy group.

Table 4
F values (p values) for the effects and interactions of load, schoolbag type (Sbag) and body mass index (BMI) for the average angle of the thorax, pelvis, hip and knee over the gait cycle. Significant effects are in bold.

		BMI	Load*BMI	Sbag*BMI	Load*Sbag*BMI
THORAX	Sagittal	0.03 (0.91)	0.82 (0.49)	3.11 (0.08)	1.36 (0.51)
	Frontal	0.15 (0.74)	1.71 (0.31)	0.08 (0.77)	0.36 (0.78)
	Transverse	0.87 (0.39)	0.59 (0.62)	3.29 (0.07)	1.57 (0.21)
PELVIS	Sagittal	0.81 (0.37)	1.07 (0.18)	0.11 (0.74)	1.91 (0.14)
	Frontal	0.06 (0.81)	0.75 (0.52)	0.21 (0.65)	0.29 (0.81)
	Transverse	0.06 (0.81)	0.49 (0.69)	0.28 (0.59)	0.12 (0.95)
HIP	Sagittal	2.07 (0.15)	2.49 (0.07)	0.51 (0.47)	2.22 (0.10)
	Frontal	0.06 (0.81)	0.34 (0.79)	2.04 (0.16)	1.71 (0.18)
	Transverse	**13.8 (0.001)**	1.69 (0.18)	**11.7 (0.001)**	**3.97 (0.01)**
KNEE	Sagittal	0.09 (0.77)	0.41 (0.75)	0.00 (0.99)	0.48 (0.70)
	Frontal	**10.3 (0.002)**	1.49 (0.22)	1.47 (0.23)	0.62 (0.61)
	Transverse	2.98 (0.09)	0.49 (0.68)	0.81 (0.36)	1.23 (0.31)

were very similar. This finding supports the results obtained in previous studies, which did not find a significant evidence of BMI on the rating of pain/discomfort after carrying a backpack (Adeyemi et al., 2015; Dockrell et al., 2015; Aprile et al., 2016). In fact, a higher proportion of healthy-weight children than obese/overweight children reported fatigue when carrying their own schoolbags to school. Therefore, additional factors other than BMI should be considered in the psychosocial perception of load carriage.

Regarding spatiotemporal gait parameters, no significant differences were found between healthy-weight and obese/overweight children, in concordance with previous studies that reported no significant differences in cadence, stride length, stance phase, or double stance phase (Nantel et al., 2006). In contrast, other studies concluded that overweight children spent an increased amount of time in ground contact compared to healthy-weight students (Hills and Parker, 1992). In our study, differences were found in velocity, with healthy-weight children reducing their velocity in all three backpack load conditions compared to the control condition; additionally, this group walked faster in the trolley conditions with 10 and 20% BW than in the backpack conditions. In concordance with the results found in this current study, a prior study reported that students remained closer to their unloaded velocity when using a school trolley than when carrying a backpack with the same load (Orantes-Gonzalez and Heredia-Jimenez, 2017). Furthermore, in the obese/overweight group, none of the analysed spatiotemporal gait variables changed as a function of the type of schoolbag.

With respect to kinematic adaptations, the obese/overweight children had greater internal rotation movements of the hip than the healthy-weight children, in concordance with a previous study (Hills and Parker, 1992). Additionally, in all three load conditions, the school trolley, compared to the backpack, allowed the obese/overweight children to maintain hip rotation movement relatively similar to unloaded walking, in concordance with previous studies (Orantes-Gonzalez et al., 2017, 2019). The frontal plane of the knee showed differences between BMI groups. The obese/overweight group had higher values of knee adduction than the healthy group, as reported in previous studies (McMillan et al., 2009, 2010). In addition, postural changes were observed between BMI groups in the control condition and all three load conditions. Therefore, the two BMI groups appears to have similar responses to loads.

The results of the RPE analysis indicated that the obese/overweight group had a lower perception of effort than the healthy-weight group when pulling the trolley with 10% and 15% BW, corroborating the

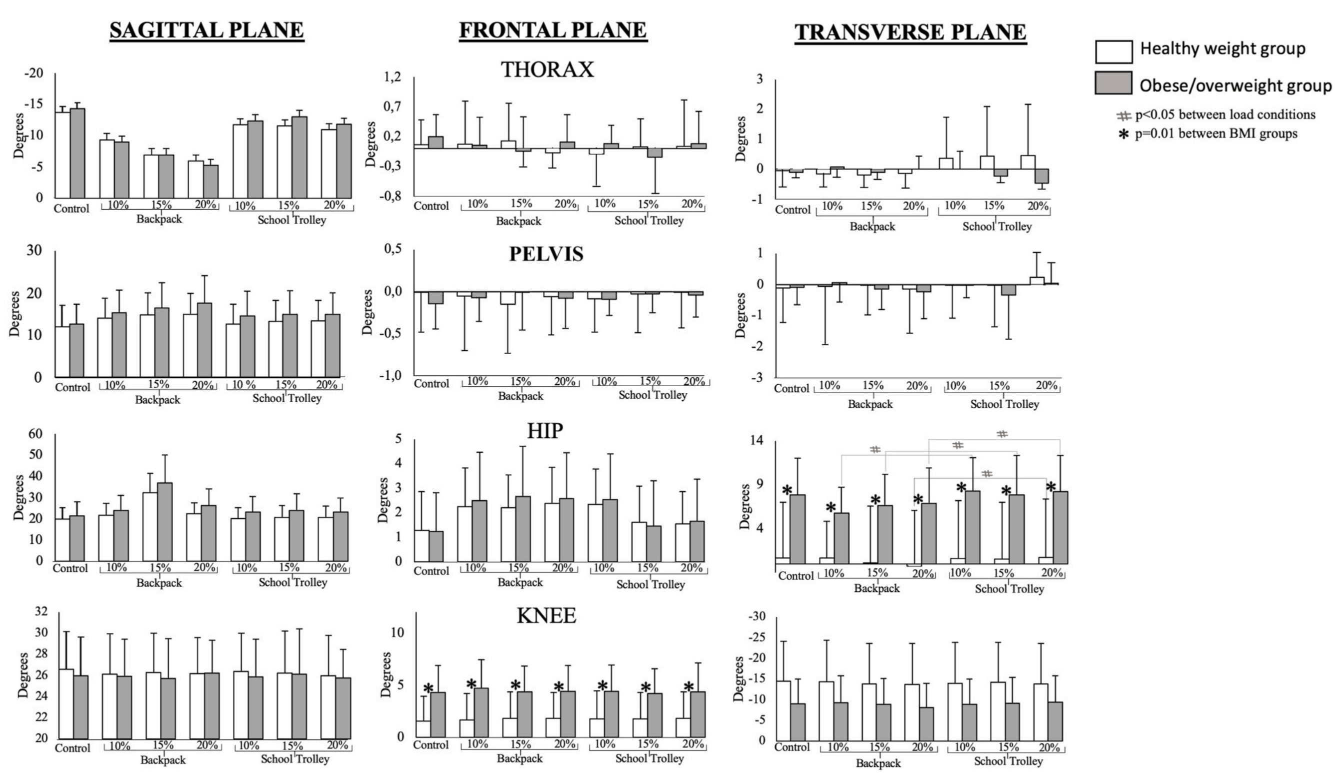

Fig. 3. Average angles of the thorax, pelvis, hip and knee in the sagittal, frontal and transverse planes over the gait cycle. Positive values indicated the flexion, adduction/right lateral bending and internal rotation of the different joints. *: p < 0.05 between body mass index groups. #: p < 0.05 between load conditions.

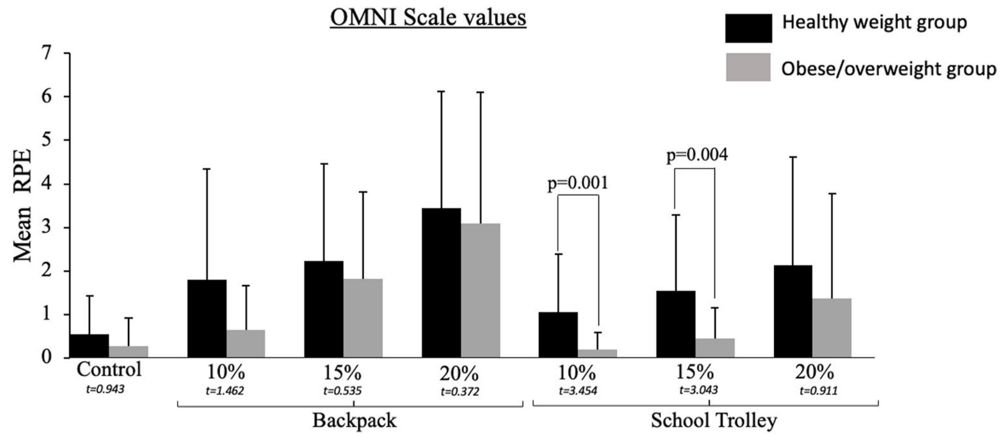

Fig. 4. Rate of perceived exertion for the different experimental conditions in the healthy and obese/overweight groups. t: independent *t*-test value of each comparison.

findings of Laurent et al. (2019) in which overweight children reported lower RPE values during submaximal cycling than healthy children did. The reduced effort perceived by the obese/overweight group could also indicate the suitability of school trolleys for that group of children.

In addition, the results obtained in this study indicated that obese/overweight and healthy-weight children have similar response to load regarding gait, posture and RPE when they use a backpack or school trolley. Although more research is needed to show conclusively that the trolley is a preferable way of transporting school supplies in obese and overweight students, as was previously reported for healthy-weight students (Orantes-Gonzalez et al., 2017, 2019; Orantes-Gonzalez and Heredia-Jimenez, 2017).

Although some previous studies have indicated that the maximum weight for overweight students' backpacks should be less than that for healthy-weight students' backpacks (Adeyemi et al., 2015, 2017), our study did not support those weight restrictions based on the results found in the spatiotemporal, kinematic, weight, fatigue perception, and RPE variables. Therefore, the results of this study do not corroborate the reduced backpack load recommendation for overweight students. Further studies should analyse the movement characteristics of obese males and females during load carriage to study sex-specific adaptations to loads with different types of schoolbags. In addition, heart rate measurements should be included as a physiological variable to complement the RPE values.

One limitation of this study is that BMI is not the best predictor of fitness or health; thus, it is possible that some children were not optimally grouped based on their BMI. In addition, the increased amount of soft tissue in obese/overweight children could have been an issue for marker placement or tracking. In addition, the responses to the questions about the weight of the schoolbag and perceived fatigue were negatively worded, and the answer scale was simplified compared to the original questionnaire. An additional limitation is the small sample size, which may have prevented the results for the obese/overweight group from reaching statistical significance.

5. Conclusions

Obese/overweight and healthy-weight children have similar response to load when they use a backpack or school trolley up to 20% BW, based on spatiotemporal and kinematic parameters, RPE and self-reported perceptions of schoolbag weight and fatigue. Therefore, although some previous studies indicated that the maximum backpack weight for overweight students should be less than that of their healthy-weight counterparts, our study did not support those results. Therefore, recommendations for backpack/school trolley weight should be the same for overweight, obese and healthy-weight students.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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