THE EFFECTS OF A SCHOOL BAG LOAD CARRIAGE ON GAIT KINEMATICS IN CHILDREN: A SCHOOL-BASED STUDY

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Abstract:

The main purpose of this study was to explore the impact of carrying a school bag on spatiotemporal gait parameters in a sample of primary school children. Two-hundred and twenty-one children (124 girls and 97 boys), aged 9.5±2.1 years, were randomly selected from three primary schools in the city of Brno, Czech Republic. Gait analysis without and with the school bag load carriage was performed using the Zebris pressure platform. The software generated the data for spatial (foot rotation, step length, stride length and step width) and temporal (step time, stride time, cadence and gait speed) gait parameters. The mean school bag weight was 4.86±1.21 kg. Repeated measures ANCOVA adjusted for sex and age showed that carrying a school bag resulted in a higher external left foot ($F_{1,220}$=8.390, p<.001) and right foot ($F_{1,220}$=8.791, p<.001) rotation, narrow step width ($F_{1,220}$=6.113, p<.001), longer left foot ($F_{1,220}$=5.556, p=.011) and right foot ($F_{1,220}$=4.508, p=.021) step time, longer stride time ($F_{1,220}$=3.773, p=.035), less cadence ($F_{1,220}$=3.773, p=0.038) and slower gait speed ($F_{1,220}$=4.131, p=.029). Carrying a school bag weight may change gait characteristics in school-going children, especially in temporal parameters.

Keywords: *walking, primary school students, backpack, equipment*

Introduction

At the beginning of compulsory schooling, a few significant changes start to impact the daily child's routine, especially a non-negligible load on the musculoskeletal system caused by carrying school bags (Chaudhari, Saini, Bharti, Gopinathan, & Narang, 2021; Dockrell, Simms, & Blake, 2015a).

As walking is one of the main biological tasks for humans, constant heavy loads combined with overweight and obesity may lead to pain or discomfort in the lower limbs (Hills, Hills, Hennig, McDonald, & Bar-Or, 2001). Carrying heavy school bags is also associated with a multitude of bodily distresses and health problems such as musculoskeletal discomfort, posture imbalance, and back or shoulder pain (Bika-Lélé, et al., 2020; Delele, Janakiraman, Bekele Abebe, Tafese, & van de Water, 2018; Dockrell, et al., 2015a; Catan, et al., 2020; Kasović, Gomaz, & Zvonar, 2019). At school age, children's musculoskeletal systems are still developing and are negatively influenced by many factors, such as inappropriate sitting positions and lack of physical activity (Negrini & Carabalona, 2002; Siambanes, Martinez, Butler, & Haider, 2004).

School-going children load their school bags with books, workbooks, school supplies, gym items, slippers, water bottles, etc. Carrying an excessive load is a health problem for children of both sexes (Kasović, et al., 2019), including musculoskeletal pain, discomfort and fatigue (Bika-Lélé, et al., 2020; Catan, et al., 2020; Delele, et al., 2018; Dockrell, Blake, & Simms, 2015b; Kasović, Štefan, & Zvonar, 2019a), but it must be remembered that school bags have more health risk factors than just the weight (Kasović, Zvonar, Gomaz, Bolčević, & Anton, 2018). Other important factors of school bags concerning children's health are its size, duration and method of carrying it, (in)correct placement on the back, and elasticity of the straps (Huang, Sui, & He, 2020; Kasović, et al., 2018). Abnormal gait in relation to heavy load generally results in impaired muscle strength, increased or decreased range of motion of lower extremities and increased energy expenditure, which leads to a higher incidence of injury, pain and discomfort, especially in the lower back, hip, knee and ankle regions of the body (Bika-Lélé, et al., 2020; Catan, et al., 2020; Delele, et al., 2018; Dockrell, et al., 2015a; Kasović, et al., 2019; Siambanes, et al., 2004).

As heavy school bags have become a widespread problem, many studies have been conducted to determine the safe backload limit to carry for school-going children. School bags are in most cases identified as overweight (Kasović, et al., 2019a; Khallaf, 2016) with regard to the ratio between the total body weight of the child and the weight of his/her backpack. Many researchers agree with the statement that the school bag should not exceed 10% of the child's total body weight (Catan, et al., 2020; Song, Yu, Zhang, Sun, & Mao, 2014). Guidelines for recommended loads are mostly within 10-15% of the child's total body weight (Kasović, et al., 2018), although global recommendations have not yet been established (Dockrell, et al., 2015a).

In recent decades, the concern about heavy school bags has been growing among health practitioners, parents, and educators to reduce the weight of school bags that may cause serious effects on children's gait (Chow, et al., 2005; Gupta, Kalra, & Iqbal, 2016). The foot is considered as an essential part of the body (Scott, Menz, & Newcombe, 2007). Furthermore, it absorbs various shocks over irregular surfaces and maintains forward propulsion (Kasović, Štefan, Borovec, Zvonař, & Cacek, 2020).

An individual's gait gradually changes from an early age, and studies do not coincide with at what age children achieve adult-like gait patterns. However, research indicates that it is at the age between 5-7 years (Kasović, et al., 2020). Several studies have investigated the relationship between school bag weight and health-related issues, including back (Bika-Lélé, et al., 2020; Negrini & Carabalona, 2002) and musculoskeletal pain (Chen & Mu, 2018; Delele, et al., 2018; Dockrell, et al., 2015b; Khallaf, 2016).

Most previous research aiming to establish the effects of carrying excessive weight on gait kinematics and kinetics have been conducted among military personnel (Attwells, Birrell, Hooper, & Mansfield, 2006; Birrell & Haslam, 2010; Singh & Koh, 2009). In general, heavier loads lead to small-to-moderate changes in kinematic and moderate-to-high changes in kinetic parameters. Although carrying heavy loads in children represents a public health problem, to date little evidence has been provided regarding gait changes under different loading conditions.

In recent years, attention has been devoted to considering the connections between carrying school bags and changes in spatiotemporal and kinetic gait parameters (Ahmad & Barbosa, 2019; Kasović et al., 2018). In a study by Ahmad and Barbosa (2019), findings showed that heavier school bag loads were associated with the most common parameters used to describe gait kinematics, i.e., slower gait velocity and longer duration of the stance, swing and double support phases, and a smaller number of steps per minute, while no changes in the stride length were observed. In the same study, the authors found significant increases in the contact area, contact time, pressure-time and force-time integrals, and mean plantar pressure, when heavier school bag loads were added, especially beneath the toe and midfoot regions of the foot (Ahmad & Barbosa, 2019). A study by Kasović et al. (2018) showed that walking with a school bag changes the plantar pressure patterns in children when compared to walking without an external load, which was also confirmed by previous evidence (Connolly, et al., 2008; Hong, Li, Wong, & Robinson, 2000a; Pau, et al., 2015).

Combining heavy external forces with changes in gait kinematics has been shown to highly impact locomotor apparatus in children (Ahmad & Barbosa, 2019). Based on the aforementioned studies, the findings on the effects of carrying loads and gait changes in school-going children seem to be inconclusive. By defining potential effects, public health policies may be able to recommend an appropriate school bag mass and school supply positioning within the school bag, in order to lower potential stress-related injuries and changes in locomotor patterns. Another problem lies in the fact that the relative load carried by school-going children has been considered in previous studies as one of the contributory factors to developing musculoskeletal problems among this age group (Bika-Lélé, et al., 2020; Delele, et al., 2018; Dockrell, et al., 2015a), including changes in head/neck positioning and deviations in spinal posture and trunk muscle activity levels, which all affect gait patterns. Since children go through rapid musculoskeletal and physical development, carrying heavy school bags has drawn public health concerns raised by parents, educators and health-related professionals. Although there have been studies controlling for age and sex in the literature, they do not deal with the issue of carrying school bags (McKay, et al., 2017).

Therefore, the main purpose of this study was to explore the effects of carrying a school bag on spatiotemporal and kinematic gait parameters in a sample of primary school children (6-14 years of age). As part of this, several sex and age-specific kinematic foot variables in primary school children were established. According to the aforementioned, we hypothesized that gait characteristics under the 'school bag load' would significantly change, compared to the 'no load' condition.

Methods

Study participants

For the purpose of this cross-sectional study, we randomly approached to five elementary schools in the city of Brno, Moravska region, Czech Republic. A total of 452 requests for participation, containing a detailed description of the purposes of the study and the experimental protocol, were delivered to all the pupils enrolled in three primary schools in Brno (Czech Republic). Of these, 221 families expressed formal acceptance by signing an informed consent form and 221 children (124 girls and 97 boys), aged 9.5±2.1 years, from the Czech Republic were included in this study. To compute the sample size with G*power software (Kang, 2021), to assume a medium effect (f=0.25), 5.0% error probability and 80.0% statistical power with two measurements ('no load' vs. 'school bag load'), two covariates (sex and age), and correlation between the two measurements of 0.5, these outputs yielded a sample size of at least 211 participants. Inclusion criteria were the following: (i) participants (boys and girls) must carry a school bag on a daily basis (on their back); (ii) participants aged between 6-14 years; (iii) no clinical diagnosis of musculoskeletal or neurological diseases. Individuals diagnosed with acute or chronic conditions that prevented them from attending physical education classes as well as individuals lacking complete data, were excluded.

Conforming with the General Data Protection Regulation (GDPR), all the procedures were anonymous and in accordance with the Declaration of Helsinki, where all participants were marked in the software under a unique code. This study was approved by the Ethical Committee of the Faculty of Sports Studies, Czech Republic (Ethical code number: 0560/2018).

Gait analysis

Zebris FDM (Force Distribution Measurement) plantar pressure platform was used to assess the spatiotemporal gait parameters (FDM; GmbH, Munich, Germany; number of sensors: 11,264; sampling rate: 100 Hz; sensor area: 149 cm×54.2 cm; Figure 1) (Internet page: https://www.zebris.de/fileadmin/Editoren/zebris-PDF-Manuals/Medizin/Software/Alte_ Versionen/ Manua 1_zebris_ FDM_1.16.x_R1_EN_web.pdf). Each participant was instructed to walk barefoot at a comfortable and natural speed across the platform, looking straight forward and without targeting the platform. After completing the first trial and reaching the end of the walkway, the participant needed to turn 180° around and continue to walk again over the platform. The protocol was repeated for six trials, where at least two footprints on the platform were always recorded, as recommended by previous evidence (Kasović, et al., 2020). It has been suggested that barefoot gait analysis is sufficient for clinical studies and is safe and sensitive for the platform (Van Alsenoy, et al., 2019).

The following variables were generated by the FDM software for this study: foot rotation (°)_left and right foot; step length (cm)_left and right foot (the distance from the heel of one foot to the heel of the other foot); stride length (cm; the distance from the heel of the left foot to the heel of the next left foot), step width (cm; the distance between the feet), step time (s)_left and right foot (the time from the contact of one heel of the foot to the heel of the other foot); stride time (s; the time from the contact of the left heel to the heel of the next left foot), cadence (steps/min) and gait speed (km/h). For accuracy, foot rotation (°) describes the angle between the longitudinal axis of the foot and the walking/running direction whereby a negative value characterizes inward rotation and a positive value characterizes outward rotation (Van Alsenoy, et al., 2019). Of note, the internal consistency between the trials was >0.90 for all the study variables and both conditions, while previous studies have shown that Zebris FDM platform has acceptable test-retest reliability and validity properties (Van Alsenoy, et al., 2019). This study was conducted at the end of the year 2020 when participants were measured on a random school day (Monday-Friday) in their schools during physical education classes in the morning hours between 9:00-11:00 a.m. During the testing, children wore light clothes (a T-shirt with shorts and socks, which were removed when walking over the platform). The school bags (4.86 kg ± 1.21) in all cases were worn over two shoulders. Relative schoolbag weight was calculated by the following formula:

(school bag weight/child weight)*100.

Procedure

The participants started barefoot walking 4.5 meters ahead of the pressure platform and finished the trial 4.5 meters after the end of the platform to preserve acceleration and deceleration in gait. After completing the first task, the same task was repeated while carrying the school bag. Gait assessments were measured at the participant's school. Before the measurement itself, each participant crossed the platform several times to avoid misunderstandings about treads and speed. Additionally, all participants were required to look straight ahead without targeting the pressure platform. The measurement protocol was done with randomization, where participants were not familiar with the order of testing nor with the testing condition ('no load' vs. 'schoolbag load'). The testing procedure lasted from September to December 2020.

Data analysis

The basic descriptive statistics are presented as mean ± standard deviation (SD). The Kolmogorov-Smirnov test was calculated for all experimental data before inferential testing. The assumptions of normality and sphericity to run the analyses were met. Repeated measures ANCOVA with one factor (sex), one covariate (age) and two conditions (no load and school bag load) was used to calculate the differences. Finally, the effect size (ES) ranges from small (<0.3), through medium (0.3-0.5) and strong (0.5-0.8) to very strong (>0.80), determined by Cohen's d (1988). The significance was set at p≤.05. The measured data were transformed directly from Zebris software into a raw data format. All analyses were performed in Statistical Packages for Social Sciences, version 22 (IBM, Chicago, IL, USA).

Results

Basic descriptive statistics of the study participants are presented in Table 1. Boys were taller, heavier and carried heavier school bags (kg) compared to girls.

Figure 1 shows the mean and SD differences in spatial gait parameters between the two conditions: 1) 'no load' vs. 2) 'school bag load'. When carrying the school bag load, significant main effects for the following spatial parameters were found: increases in left foot (89.6%, $F_{1,220}$=8.39, ES=0.30, p<.001) and right foot (74.1%, $F_{1,220}$=8.79, ES=0.27, p<.001)

Table 1. Basic descriptive statistics of the study participants (N=221)

Basic study variables	Total (N=221)	Boys (n=97)	Girls (n=124)	*p* for Gender
	mean ± SD	mean ± SD	mean ± SD	
Age (years)	9.5 ± 2.1	9.7 ± 2.1	9.3 ± 2.0	0.105
Height (cm)	140.3 ± 13.3	142.4 ± 13.5	138.6 ± 13,0	0.082
Weight (kg)	35.5 ± 12.07	37.14 ± 11.9	34.3 ± 12.1	0.062
Body mass index (kg/m²)	14.4 ± 3.1	18.3 ± 2.9	17.9 ± 3.2	0.041
Weight of a school bag (kg)	4.86 ± 1.21	5.04 ± 1.25	4.7 ± 1.2	0.038
Relative school bag weight (%)	14.5 ± 3.8	14.2 ± 3.5	14.7 ± 4.0	0.317

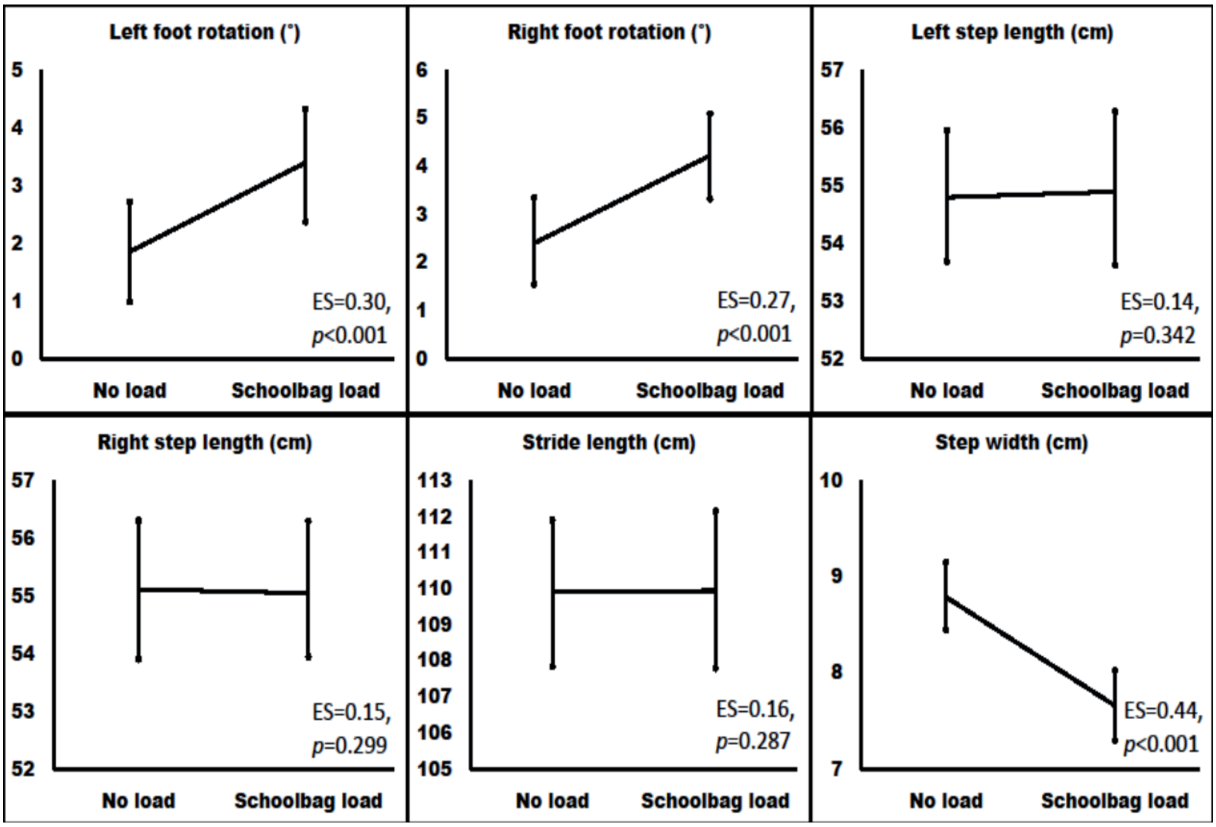

Figure 1. Differences in spatial gait parameters between two conditions: 1) 'no load' vs. 2) 'school-bag load' of the study participants (N=221).

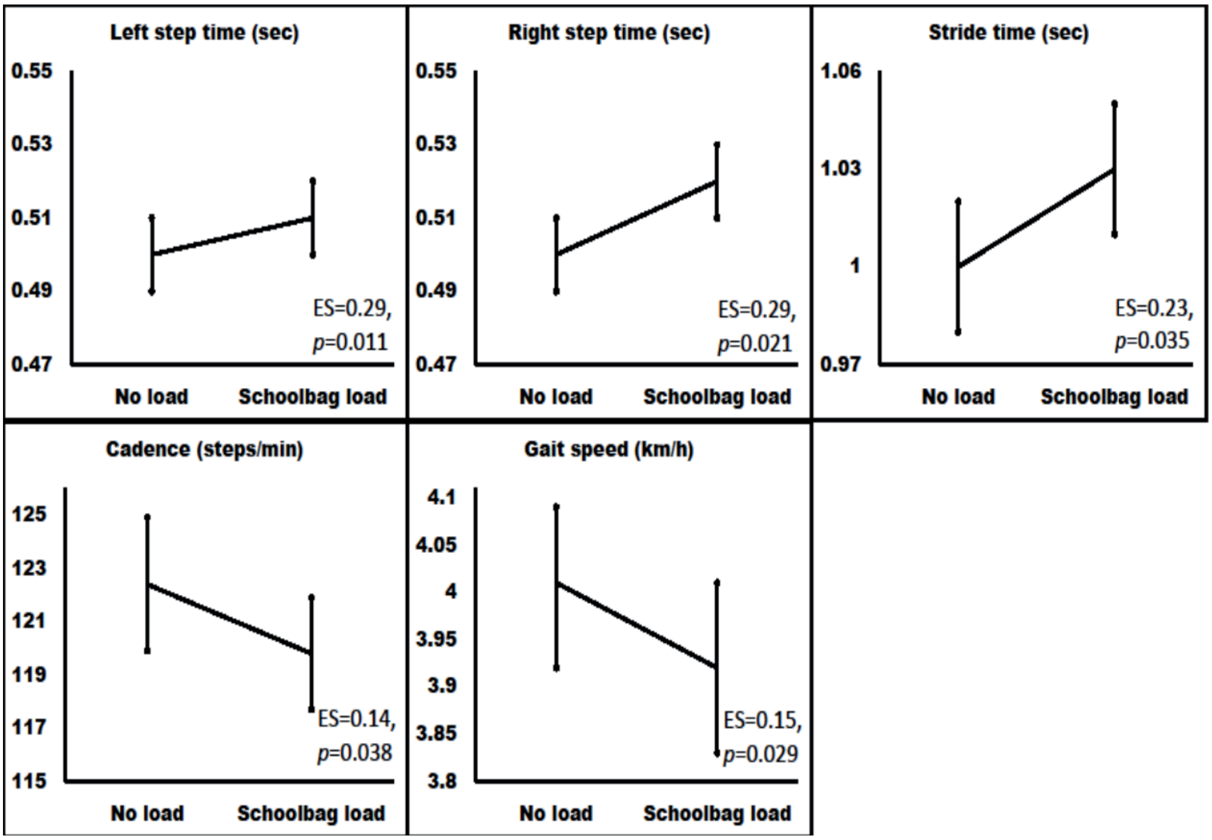

Figure 2. Differences in temporal gait parameters between two conditions: 1) 'no load' vs. 2) 'school-bag load' of the study participants (N=221).

rotations, and a decrease in step width (12.9%, $F_{1,220}$=6.11, ES=0.44, p<.001) were observed. No significant changes in other spatial gait parameters were observed (p<.05).

Changes in temporal gait parameters under the school bag weight are presented in Figure 2. When carrying a school bag load, significant main effects for the following temporal parameters were found: increases in left foot (4.0%, $F_{1,220}$=5.57, ES=0.29, p=.011) and right foot (4.0%, $F_{1,220}$=4.51, ES=0.29, p=.021) step time and stride time (3.0%, $F_{1,220}$=3.81, ES=0.23, p=.035) as well as decreases in cadence (1.8%, $F_{1,220}$=3.77, ES=0.14, p=.038) and gait speed (2.2%, $F_{1,220}$=4.13, ES=0.15, p=.029). When sex and age were put separately and simultaneously into the model, no significant interactions between time, sex and age were observed.

Discussion and conclusions

The main purpose of this study was to explore the effects of carrying a school bag load on spatio-temporal gait kinematic parameters in a sample of primary school children. The main findings of this study are: (1) carrying a school bag load increases external left and right foot rotation, left and right step time and stride time, while it decreases step width, cadence and gait speed; 2) the significant effects are only observed for time, while time*sex and time*age interactions remained non-significant.

Since this is the first sex- and age-specific study examining spatiotemporal gait parameters in primary school-aged children, it is somewhat difficult to compare the results with previous literature. Most of previous studies have focused on biomechanical foot parameter changes while walking with school bags (Connolly, et al., 2008; Hong &Brueggemann 2000b; Kasović, et al, 2018; Pau, et al., 2015); however, these have been mostly based on the changes in plantar pressure distribution. Connected with the field of gait kinematics, there were no significant differences nor time effects in spatial and temporal gait kinematics when walking without and with school bags under two conditions (elastic and non-elastic straps) (Huang, et al., 2020). Ahmad and Barbosa (2019) conducted the measurement on a relatively small sample size (N=57) and suggested that gait kinematics in children was affected by carrying gradually heavier loads in school bags. Specifically, heavier school bag loads led to lower cadence and slower gait speed, compared to the 'no load' condition. Indeed, significant and moderate main effects of the heavier load on slower gait speed, lower cadence, and longer durations of the stance, swing and double support phases were shown, while no significant main effects on the stride length were observed (Ahmad & Barbosa, 2019).

Although we found significant changes in some spatial and temporal parameters, the lack of change in other gait parameters with increasing load points to hypothetical adaptations at physiological and kinetic responses. Evidence suggests that increasing loads lead to cardiovascular, respiratory and electromyography adaptations (Al-Khabbaz, Shimada, & Hasegawa, 2008; Li, Hong, & Robinson, 2003). Similar findings have been observed previously (Ahmad & Barbosa, 2019; Connolly, et al., 2008; Hong, et al., 2000; Pau, et al., 2015). It should be noted that the ES values obtained in this study between the two conditions were only trivial to small, which coincides with what was reported previously (Ahmad & Barbosa, 2019; Hong, et al., 2000a; Pau, et al., 2015). The lack of larger effects in the spatiotemporal gait parameters may be explained by children's physiological and kinetic adaptations (Ahmad & Barbosa, 2019). For example, it has been suggested that energy expenditure increases with heavier loads, especially from 15.0% of body weight onwards (Hong, et al., 2000a). A load change in our study (14.5% of total body weight) resulted in significant changes, which could be also explained by children adapting to a new set of higher motor control constraints (Ahmad & Barbosa, 2019). A study by Chow et al. (2005) exhibited similar results, where gait speed and cadence decreased significantly with increasing school bag load, while double support time increased. However, there is still no clear consensus on the maximum load to be carried by children in order to prevent changes in spinal posture, thoracic kyphosis, ground reaction forces, physical discomfort and muscle activity.

Although some studies recommend a load of 10% of the child's body weight (Perrone, Orr, Hing, Milne, & Pope, 2018) to be the top-ceiling point, we were unable to determine how small difference between 'no load' vs. 'a school bag load' would be enough to affect children's health. However, trivial to small ES obtained in our study might be the first step in determining recommendations for a relative school bag weight in school-going children. Since both spatiotemporal and kinetic gait parameters change under loading conditions of 10 to 20% (Perrone, et al., 2018), future research should be able to define optimal cut-off points of relative school bag weight and minimal clinically important differences influencing negative biomechanical gait changes. Also, we observed non-significant main effects for time*sex and time*age interactions, which may be explained by a relatively small sample size, different sex/age ratio within group and not controlling for other physiological (maturity status, body composition) or environmental factors (school bag characteristics). Due to these shortcomings, we were unable to further examine the nature of non-significant interactions; however, the findings suggest that sex and age did not have a significant role in affecting the magnitude of change between 'no load' vs. 'school bag load' in primary school-aged children.

Future research

It has been well-documented that load carriage may change gait patterns (Ahmad & Barbosa, 2019; Chow, et al., 2005; Kasović, et al., 2020) contributing to negative health-related outcomes, like musculoskeletal pain and discomfort (Bika-Lélé et al., 2020; Chaudhari, et al., 2021; Delele, et al., 2018; Dockrell, et al., 2015c). Indeed, heavy loads carried by children at early age may contribute to larger stress fractures in lower limbs and spine, causing stiffness and pain, especially in the lower back. Moreover, excessive school bag load can in long-term result in deteriorating biomechanical gait patterns (Delele, et al., 2018; Dockrell, et al., 2015a). Thus, school bag-loaded walking and running in daily life may indirectly increase the risk of lower extremity injuries, indicating that school bags may increase gait instability and posture compensations, which may lead to injuries and pain, especially in the lower back and lower extremities (Wang, et al., 2023).

Along with biomechanical and structural changes, carrying heavy loads has been shown to impact cardiorespiratory system by increasing energy expenditure and fatigue (Hong, et al., 2000a). On the other hand, a recent systematic review by Yamato, Maher, Traeger, Wiliams, & Kamper (2018) has shown that school bag characteristics such as weight, design and carriage method do not increase the risk of developing back pain in children and adolescents. Therefore, future research should explore other potential mechanisms which connect an external load with gait characteristics changes and pain.

Limitations of the study

This study is not without limitations. First, to give the possibility to assess natural changes in individual growth as our participants were children, a longitudinal study should have been conducted. By using a longitudinal design, we would have been able to examine causal differences and possible follow-up effects of school bag loads on spatiotemporal foot parameters. Since previous studies have shown that walking with an unusual amount of load may lead to musculoskeletal injuries (Chaudhari, et al., 2021; Hills, et al., 2001), future research should explore longitudinal associations between school bag loads and the incidence of lower- and upper-body injury risks. Second, the real school bag of each child was used for the measurement to obtain the % of total school bag weight of the child. Our calculations do not apply to the specific weight for a particular person, correct placement on the back or the control of proper size of the bag; therefore, our results are relative to the mean school bag weight which was 14.5%. Also, the measurement was one-off (which allowed a larger number of participants), so it could be to some extent influenced by the current state of each child (e.g., his/her mood state). Suitable improvement for more optimal results would be to measure the children repeatedly. Indeed, a deeper insight into gait changes could be gathered by using motion-capture systems with 3-D analyses and muscle activity movements in frontal, sagittal and transversal planes. Although previous studies have confirmed the reliability and validity properties of the Zebris platform, this study lacked test-retest and correlating analyses with other motion systems. Next, the load of the school bag was the target of the study and future research should take care of including the condition of the 'empty school bag' to help eliminate the effect of the school bag itself. We were unable to compare values of biomechanical foot parameters with other normative data in children since such data are yet to be established. Finally, the nature of doing sports and being sedentary or physically active might have led to different adaptations of carrying school bags, which was not controlled for.

This is the first sex- and age-specific spatiotemporal gait kinematics study in children. The main purpose of this study was to explore the effects of carrying school bags on spatiotemporal gait parameters in a sample of primary school children. We found significant changes in several spatiotemporal gait parameters under loading conditions, pointing out that school-going children underwent significant changes in gait biomechanics while carrying school bag loads. From a public health perspective, the findings of this study should help health-related professionals and professionals who are part of the school bag ergonomics and design industry. Although the relative school bag weight was within the limits of 10 to 15 %, the position of school bag supplies and weight within the school bag should be of important interest. Also, by examining locomotor posture in annual systematic check-ups by pediatricians and physical functioning by physical education teachers, public health experts could have comparable datasets within and between the countries that may help to establish future directions and recommendations regarding the nature of school bag weight.

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