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Schoolbag Weight Carriage in Children: The Analysis of Ground Reaction Forces during Walking, Running and Jumping

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List of Publications

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Abstract

Public society and international scientific community have shown concern about the heavy scholar backpacks carried by children. The possible adverse effects on children's health of carrying those heavy loads have been in the base of that concern. Thus, the purpose of this thesis was to improve the understanding of school backpacks problem and to contribute to a solution. Specifically, it was our aims: (i) review the existing evidence concerning the characterization of backpack carrying, the known impacts and the solutions; (ii) characterize the loads that students in Portugal carry on their backpacks; (iii) understand how those loads influences the GRF acting on subjects and; (iv) propose modifications on backpack design that do not significantly modifies the main design but can attenuate the GRF magnitude increments. The main conclusions were: (i) scientific community still couldn't clearly and consistently identified the effects of carrying backpack loads on children health. There are several body structures been studied as they could be affected. Also, there are not a consensus around the load limit that children should carry, however, the limit that seems to be more often recommend is the 10% of the body weight; (ii) the population analysed, students in Portugal, often carried more load than the recommended 10% of body weight. 5th grade students carry more absolute load than the 9th grade students; (iii) the load carried influenced the ground reaction forces. That influence was different in function of the mean of locomotion and the age/school grade, and (iv) with the backpack modification, the introduction of elastic material on the backpack straps, were verified changes on the influence of the backpack carrying in GRF, mainly the decrease of force peaks and loading rate. The main findings of this study confirmed the idea that children in Portugal may be carrying heavier loads on their backpacks than they should, especially the younger ones, and that it influences the ground reaction forces acting on them. However, we saw that is possible to introduce discrete modifications on typical backpacks than can attenuate that effect. It is needed to study, in the future, the way that benefits can be maximized and should not be forgiven the organization/pedagogical measures that may reduce the backpack load.

Key words

Backpack, ground reaction forces, children, health, Biomechanics.

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Resumo

A comunidade científica internacional e a sociedade em geral, têm manifestado preocupação relativamente às elevadas cargas transportadas pelos alunos diariamente para a escola. Os possíveis efeitos adversos do transporte dessas cargas na saúde das crianças têm estado na base da preocupação. Assim, o intuito deste trabalho foi melhorar o conhecimento acerca do problema das mochilas escolares e contribuir para uma solução. Especificamente, foram nossos objetivos: (i) rever as evidências existentes concernentes à caracterização do transporte das mochilas, os impactos conhecidos e as soluções propostas; (ii) caracterizar as cargas que os alunos em Portugal transportam; (iii) perceber como essas cargas influenciam as forças reativas do solo que atuam sobre as crianças, e (iv) propor e estudar modificações no design das mochilas que não o alterem significativamente mas que consigam atenuar o incremento da magnitude das forças reativas do solo. As principais conclusões foram: (i) a comunidade científica ainda não identificou de forma clara e consistente os efeitos do transporte das mochilas na saúde das crianças. São várias as estruturas do corpo que estão a ser estudadas como pudendo ser afetadas, mas os resultados não são consistentes. Também não existe consenso acerca do limite de carga que as crianças devem transportar, porém, o limite que mais é recomendado na literatura é 10% do peso corporal; (ii) a população analisada, alunos em Portugal, transportam frequentemente cargas superiores aos 10% recomendados. Os alunos mais novos, do 5º ano de escolaridade, transportam cargas absolutas superiores aos alunos do 9º ano; (iii) a carga transportada influenciou as forças reativas do solo. Essa influência variou em função do tipo de locomoção e do ano de escolaridade, e (iv) com a modificação proposta para a mochila, a introdução de material elástico nas alças, verificaram-se alterações na influência sobre as forças reativas do solo, principalmente a diminuição da magnitude dos valores de pico e da taxa de carga. Estas conclusões confirmaram a noção de que as crianças podem estar a transportar cargas demasiado elevadas para a escola, especialmente os mais novos, e que isso influencia as forças reativas do solo que atuam sobre eles. Contudo, vimos que é possível realizar alterações discretas nas mochilas escolares típicas, que podem atenuar esse efeito. Será necessário estudar a forma como essa vantagem poderá ser maximizada, sem esquecer as medidas organizacionais e pedagógicas que podem reduzir a carga a ser transportada.

Palavras-chave

Mochila, forças reativas do solo, crianças, saúde, biomecânica.

Resumen

La comunidad científica internacional y la sociedad en general han expresado su preocupación por las elevadas cargas que llevan los estudiantes a diario a la escuela. Los posibles efectos adversos del transporte de estos cargamentos sobre la salud de los niños han sido motivo de preocupación. Así, el objetivo de este trabajo fue mejorar el conocimiento sobre el problema de las mochilas escolares y contribuir a una solución. Específicamente, nuestros objetivos fueron: (i) revisar la evidencia existente sobre la caracterización del transporte de mochila, los impactos conocidos y las soluciones propuestas; (ii) caracterizar las cargas que llevan los estudiantes en Portugal; (iii) comprender cómo estas cargas influyen en las fuerzas reactivas del suelo que actúan sobre los niños, y (iv) proponer y estudiar cambios en el diseño de las mochilas que no lo alteren significativamente, pero que logren mitigar el aumento de la magnitud de las fuerzas reactivas del suelo. Las principales conclusiones fueron: (i) la comunidad científica aún no ha identificado clara y consistentemente los efectos de llevar mochilas, sobre la salud de los niños. Se están estudiando varias estructuras del cuerpo que pueden verse afectadas, pero los resultados no son consistentes. Tampoco existe consenso sobre el límite de carga que deben llevar los niños, sin embargo, el límite más recomendado en la literatura es el 10% del peso corporal; (ii) la población analizada, estudiantes en Portugal, transporta con frecuencia cargas superiores al 10% del peso corporal. Los estudiantes más jóvenes, a partir del 5º año de escolaridad, soportan cargas absolutas más elevadas que los del 9º año; (iii) la carga transportada influyó en las fuerzas reactivas del suelo. Esta influencia varió según el tipo de locomoción y el año de escolaridad, y (iv) con la modificación propuesta a la mochila, la introducción de material elástico en las correas, hubo cambios en la influencia sobre las fuerzas reactivas del suelo, especialmente la disminución de la magnitud de los valores máximos y la tasa de carga. Estos hallazgos confirmaron la noción de que los niños pueden llevar cargas demasiado altas a la escuela, especialmente los más pequeños, y que esto influye en las fuerzas reactivas del suelo que actúan sobre ellos. Sin embargo, hemos visto que es posible realizar cambios discretos en las típicas mochilas escolares que pueden mitigar este efecto. Habrá que estudiar cómo se puede maximizar esta ventaja, sin olvidar las medidas organizativas y pedagógicas que pueden reducir la carga a transportar.

Palabras-clave

Mochila, fuerzas reactivas del suelo, niños, salud, biomecánica.

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List of Abbreviations

BMI	Body mass index
CI	Confidence interval
GRF	Ground reaction forces
ES	Effect size
Hz	Hertz
m	Meters
min	Minute
SD	Standard deviation
η_p^2	partial eta squared

Chapter 1. General Introduction

Portuguese public society has shown concern about the heavy scholar backpacks carried by children and alerted the governmental institutions. Even a public petition subscribed by dozens of thousands of people, institutions and organizations, in health sector occurred in Portugal (PetiçãoPública.com). To respond this alert, the Portuguese parliament approved by unanimity eleven measures that should be implemented. Until now the national government accomplished one of them, emitting recommendations for students and parents when buying and using school backpacks. These recommendations were published through the National Health System (SNS, 2019), launched online (SNS) and on a eBook format (SNS, 2018). Thus, the possible adverse effects of the heavy scholar backpacks are a public health concern and deserves the best attention by the Portuguese educational and scientific community.

Backpacks weight is not just a national concern, but discussed by several countries and international scientific community. The approach to study this problem has been fundamentally by the quantification of the load carried by students on their backpacks (Al-Hazzaa, 2006; Bryant et al., 2014; Lasota, 2014), the kinematics analysis of the backpack influence on posture on standing position and on walking (Chansirinukor et al., 2001; Chen et al., 2018; Dahl et al., 2016), kinetics analysis by the study of plantar pressure and ground reaction forces (GRF) (Ahmad et al., 2019; Gelalis et al., 2012; Mosaad et al., 2015; Pau et al., 2015), surveys about a possible influence on back pain (Dockrell et al., 2015; O'Keeffe et al., 2018; White et al., 2007) and a few about possible alternatives to the traditional school backpacks (Mackie et al., 2003; Mallakzadeh et al., 2016; Ramadan et al., 2013).

Concerning to the amount of load carried by students, it varies between countries where the studies are performed (Al-Hazzaa, 2006; Brzek et al., 2017; Whittfield et al., 2001). There are several factors that are different among the study's methodology, such as the school year/age analysed, difficulting the comparisons. However, there is a common conclusion: students carry an excessive load on their backpacks. This conclusion is usually based on the recommendation, also shared by the World Health Organization (OMS) (SNS), that the children may not carry more than 10% of total body mass (Al-Hazzaa, 2006; White et al., 2007).

The kinematics analysis has mainly focused on spine deformations, especially neck and head posture modifications (Kim et al., 2008; Mosaad et al., 2015), and on gait modifications (Ahmad et al., 2019; Chow et al., 2005) produced by the backpack. Regardless the focus of the kinematics analysis, modifications on posture and gait when the backpack is added have been observed. In the same way, kinetics analysis also has been shown modifications on the plantar pressure and ground reaction forces (Castro et al., 2015; Mosaad et al., 2015). These modifications, evaluated by both kinematics and kinetics approach lead to an inevitable concern regarding health, especially in children. Moreover, the studies have shown those effects while standing and when walking. However, children use to run and jump with the backpack on. So, there's a need to better understand the kinetics and kinematics on those situations.

It generally accepted that backpacks are too heavy (Jurak et al., 2019) and that their transport lead to back pain (Calvo-Munoz et al., 2020; Yamato et al., 2018). In school students, which is a repetitive situation, carrying, as seen above, more than 10% of their body mass. Several studies have been analysed it and tried to prove that common sense illation (Calvo-Munoz et al., 2020; Yamato et al., 2018). However, the conclusions of these studies are contradictory or inconclusive and we can't affirm for sure that the load carried on the backpacks are responsible for backpain on children.

One factor that may contribute to this limitation on evidence/conclusions can be the variability of the analyzed backpack's load and the variability of ages of students among the studies. Upon that, in this research thesis is proposed to study two different school years on the same study, with the same methodology. That will allow to pre-determine the loads that are usually carried by them on their backpacks to use those loads for studying the effects that they may produce.

The study of the possible effects produced by the carrying of loads on the backpacks can be done, as described above, by several biomechanical perspectives. We decided to analyse the influence of backpack's load on ground reaction forces. This decision was taken because of the adverse influence that high ground reaction forces (GRF) levels may have on body structures, since it have been associated with lower-limb injuries (Simpson et al., 2012), inducing degradation of the biomechanical properties of the joint cartilage, but also with injuries at the spine level (Mosaad et al., 2015). Mechanical forces influence vertebral growth (Gelalis et al., 2012) and high loading rates may have adverse effects on bone health (Chen et al., 2018; Voloshin, 2000; Zadpoor et al., 2011). These effects, associated with the modifications on posture, already identified when carrying heavy backpacks, and that lead to, for example, modifications on spinal curvatures (Chow et al., 2007) and increments on compression of intervertebral disks (Li et al., 2018; Neuschwander et al., 2010), may be very significant to children health. This gain extra importance since it is about children, that are in the middle of the process of growing and development, and is known that musculoskeletal disorders in teenage years may predict future disorders, like in low back pain (Hestbaek et al., 2006; Mackenzie et al., 2003). Thus, If GRF magnitudes increase significantly when students are carrying their school backpacks, each step they do may have a negative contribute on children's health.

Looking forward, as several studies have already found increments on GRF magnitudes with the backpack carrying, the scientific community have not only being warning about the risks of carrying those heavy loads but also trying to propose and study modifications on backpack design so it may less influence children posture and gait (Lloyd et al., 2000; Ramadan et al., 2013). These proposals are mainly focused on avoid or attenuate the posture modifications. However, these studies are few and include modifications that significantly changes the design of the backpacks, difficult their adoption by the students (Mackie et al., 2003). So, we have the ambition to find and propose improvements on backpacks design that can maintain their mainly structure but can attenuate the GRF magnitudes increment.

Regarding the abovementioned, the purpose of this thesis was to improve the understanding of school backpacks problem and to contribute to a solution.

Specifically, it was our aims:
- Review the existing evidence concerning the backpack carrying;
- Characterize the loads that students in Portugal carry on their backpacks;
- Understand how those loads influences the GRF acting on subjects and;
- Propose modifications on backpack design that do not significantly modifies the main design but can attenuate the GRF magnitude increments.

The thesis is developed according to the following sequence:

- Chapter 2 presents a review based on the early studies regarding the characterization of the school backpack problem, the known impacts and the solutions proposed (study 1).
- Chapter 3 shows the experimental studies developed to accomplish the main aim of this thesis:
    - Study 2, developed to analyze the loads transported by students in their 5th and 9th grades in Portugal and to understand the impact on school load of factors like gender, age, the lunch site and the discipline of physical education, so we can better understand how to control those factors benefiting the students.
    - Study 3, the experimental study developed to analyze the effect of backpack transportation on GRFs in children during walking, running, and jumping. This effect was analyzed in two different school years.
    - Study 4, aims to propose and test adaptations on school backpacks in order to minimize GRF magnitudes increments.

After the studies presentation, a general discussion of the results is provided (Chapter 4), followed by the main conclusions (Chapter 5) and suggestions for future research (Chapter 6).

Chapter 2. Literature review

Study 1

Impact of overloaded school backpacks: an emerging problem

Abstract

Background. The possible adverse effects of overloading students' backpacks are a public concern and should be considered by the scientific and educational community. This topic has gained particular importance due to the childhood development process, which can increase the promotion of future disorders (e.g., back pain, low back pain, spinal column deviations). ***Objective***. In this brief review, we critically analyse the impact of excess load in students' backpacks and attempt to identify solutions that can be useful to minimize the effects of this problem. ***Conclusion***. It is necessary to find a viable alternative to classic backpacks that can contribute to minimizing the effects of backpack loads on children.

Keywords: School; Children; Backpacks; Overload; Future disorders

Problem definition

The potentially adverse effects of students' heavy backpacks are a public concern and must be considered by the scientific and educational community (Calvo-Munoz et al., 2020; Jurak et al., 2019; Yamato et al., 2018). The approach that has been used to study this problem has been fundamentally based on the quantification of the load carried by students in their backpacks (Al-Hazzaa, 2006; Bryant et al., 2014; Lasota, 2014), kinematic analysis of the influence of backpacks on upright posture and walking (Chansirinukor et al., 2001; Chen et al., 2018; Dahl et al., 2016), kinetic analysis by studying plantar pressure and ground reaction forces (GRF) (Ahmad et al., 2019; Gelalis et al., 2012; Mosaad et al., 2015; Pau et al., 2015) and surveys on various potential influences on back pain (Dockrell et al., 2015; O'Keeffe et al., 2018; White et al., 2007). Loads carried by students differ substantially between countries (Al-Hazzaa, 2006; Brzek et al., 2017; Whittfield et al., 2001). Several factors differ (e.g., study methodology, observed school year/age), making it relatively difficult to compare them. However, one common conclusion has arisen: students carry excessive loads in their backpacks. This conclusion is based on the recommendation also shared by the World Health Organization (SNS) that children should not carry more than 10% of their weight (Al-Hazzaa, 2006; White et al., 2007). However, the conclusions of these studies are contradictory or inconclusive, and it cannot be affirmed with certainty that backpack loads are responsible for children's back pain; therefore, more studies are required. Kinematic analyses have focused primarily on spinal deformities, particularly changes in the neck, head posture (Kim et al., 2008; Mosaad et al., 2015), and gait produced by the addition of the backpack. Regardless of the focus of the kinematic analysis, alterations in posture and gait were observed when backpacks were worn. Similarly, kinetic analyses have also demonstrated changes in plantar pressure and ground reaction forces (GRF) (Castro et al., 2015; Mosaad et al., 2015). Such modifications, evaluated by kinematic and kinetic approaches, led to inevitable health concerns, mainly because the subjects are children. Studies have also demonstrated these effects when standing and walking; however, children also run and jump while wearing their backpacks and, therefore, interest in analyzing this type of situations has emerged. In fact, mechanical forces influence spine growth (Gelalis et al., 2012), and high loading rates can negatively affect bone health (Chen et al., 2018; Voloshin, 2000; Zadpoor et al., 2011). These effects, associated with changes in posture and identified when carrying heavy backpacks, can induce alterations in the spine curvature (Chow et al., 2007; Walicka-Cuprys et al., 2015) and increases in intervertebral disc compression (Li et al., 2018; Neuschwander et al., 2010), which are particularly important because the childhood development process can lead to future disorders (e.g., low back pain) (Chow et al., 2010).

This review highlights the potentially negative impact of excessive students' backpacks loads and seeks to improve understanding of this problem and help develop solutions. To search for relevant publications, databases were used primarily (e.g., Web of Science, Scopus, PubMed). Articles written in English, Spanish or Portuguese were considered regardless of the publication date. Primary (‘student backpacks’, ‘backpack load’), secondary (‘back pain in children’) and tertiary (‘gait backpack load’, ‘posture backpack load’) keywords were used. 98 articles were initially analyzed. All articles that did not focus on the investigation or that were not directly related to the topic were excluded. According to this exclusion criterion only 60 articles were considered relevant for analysis.

Summary of previous research: pathologies associated with the use of loads in backpacks

The effects of carrying academic backpacks have been a particular concern because they are considered heavy (Jurak et al., 2019; Perrone et al., 2018). Hence, this area has been a specific focus of the scientific community (Dockrell et al., 2013). However, previous research mainly examined the field of biomechanics and focused on posture (static or dynamic) and the forces produced and acting on children when standing or walking (Liew et al., 2016).

Researchers have sought to define a load limit to be carried by students in the school context, given that changes in posture were evident, and the impact on children's health has become increasingly clear. However, there is still no consensus for the load limit recommendation. Therefore, studies have focused on metabolic effects (Hong et al., 2000), cardiorespiratory changes (Hong et al., 2000), pain reported by children (Al-Hazzaa, 2006), possible physical disability (Moore et al., 2007), postural changes (Bauer et al., 2009; Devroey et al., 2007; Mosaad et al., 2015), muscle activation (Devroey et al., 2007), changes in gait (Rodrigues et al., 2018) and GRF (Mosaad et al., 2015). The results of these different approaches have produced various backpack weight-limit recommendations (e.g., 10% of a child's body weight). This latter recommendation has persisted since 2004, after being suggested via a critical analysis carried out by Brackley and Stevenson (Brackley et al., 2004). Other study (Hong et al., 2000) concluded that there were no changes in the metabolic cost if children carried less than 10% of their body weight. However, Moore et al. (Moore et al., 2007), investigating elementary and high school students (i.e., 8–18 years old), found that higher relative backpack weights were associated with reports of back pain. Changes in electromyography, kinematics and subjective scores (Devroey et al., 2007) were also noted, as well as an increase in trunk flexion angle (Bauer et al., 2009), which influences gait and general stability (Rodrigues et al., 2018), when loads were above the recommended limit (i.e., 10% of a child's body weight). Other recommendations have also been proposed in this context. Al-Hazzaa (Al-Hazzaa, 2006) suggested a limit of 5–10% of body weight to avoid pain (e.g., shoulder and shoulder) in boys aged 6–14 years, whereas Daneshmandi et al.

(Daneshmandi et al., 2008) proposed a limit of 8% of body weight for male students aged 12–13 years because this was the limit from which cardiorespiratory changes began to be observed. Another investigation (Mosaad et al., 2015) found that carrying a backpack with a load of 7.5% of a 10-year-old child's body weight was sufficient to change head posture and GRF.

In addition, it is essential to mention that several reasons can be the cause of the excess weight carried by the students, which can originate the development of the before mentioned pathologies. One of the main reasons is related to the school curriculum. This is because, according to a previous report (Matlabi et al., 2014), younger students do not pay much attention to the subjects they will take during the day, and so they carry all their books unnecessarily. Thus, the same study suggests that parents can have a fundamental role in teaching their children not to take unnecessary material to school. Additionally, the fact that they carry full-water bottles from home can also contribute to increasing the weight of the backpacks as well as the change in social trends that today lead to the regular transportation of various electronic devices (Maynard et al., 2005).

However, even with these guidelines, it seems that there is still no recommended limit that meets consensus worldwide, and further investigations continue to be carried out to define the ideal load limit that should be carried by children (Perrone et al., 2018). Nevertheless, the possibility of not finding a universal limit has already been raised, taking into account each child's individual characteristics and existing anthropometric profile diversity (Dockrell et al., 2013). Based on current findings, the recommendation of 10% of body weight as a load limit seems, however, to be the most appropriate.

Explanation of subject matter: the effect of load variability on school backpacks

Perhaps because there is no universal recommendation for this weight limit, parents and students do not control the weight of the backpacks and, generally, students carry more than 10% of their own weight. This observation was noted in New Zealand (Whittfield et al., 2001), and Ireland, where only one third of students carried backpacks that were within the 10% body weight guideline (Dockrell et al., 2015), as well as in the United States of America(USA), where most students carried more than 10% of their body weight, and 5% carried more than 20% of their weight (Bryant et al., 2014). In Saudi Arabia, the 10% body weight guideline was exceeded by almost half of the sample (Al-Hazzaa, 2006). In Poland, the average weight borne by seven-year-old students was approximately 25% of their body weight, and 95.5% of students exceeded the 10% weight limit recommended by the Polish health authorities (Brzek et al., 2017). About half (54%) of 447 Italian students aged 6-10 years carried more than 15% of their body weight, and only 16.6% carried 10% or less (Pau et al., 2010). Greek students aged 9–14 years carried an average weight of 12.4% of their body weight (Kellis et al., 2010) and in Malta, 70% of students aged 8–13 years carried more than 10% of their weight (Spiteri et al., 2017).

It is important to note that the previous presented values are averages from each study. Negrini et al. (Negrini et al., 1999) provided a different perspective; loads carried by students were measured on each of the five or six days of the week, and maximum loads of the week were considered. These authors reported that 34.8% of six-year-old Italian students carried, at least once a week, more than 30% of their body weight. Furthermore, two aspects have merited the interest of researchers: 1) the possible tendency of one of the genders to carry more weight than the other and 2) the influence of age on loaded weights. Regarding the first aspect, studies in Greece (Kellis et al., 2010), the USA (White et al., 2007) and Iran (Dianat et al., 2013) found that girls are more likely to carry heavier backpacks. However, this trend has not been corroborated in other researches (Bryant et al., 2014; Matlabi et al., 2014; Negrini et al., 1999; Whittfield et al., 2001) and was even contradicted by a Polish study that observed a tendency for male and female students to carry slightly heavier school bags (Brzek et al., 2017).

Student age can influence backpack weights. Despite the differences in the absolute carried weights observed in different countries and school organizations, younger children were found to carry more relative weight than older ones (Lasota, 2014; Matlabi et al., 2014; Maynard et al., 2005; Whittfield et al., 2001). Even if younger children carried the same weight, they would be carrying a higher relative weight because they are smaller and lighter (Pau et al., 2010). In this regard, a critical aspect of using a backpack is its possible relationship with back pain. In fact, 80% of children who reported low back pain blamed it on an excessive school backpack weight (Skaggs et al., 2006), and biomechanical factors, such as school backpack characteristics, have traditionally been associated with back pain in children and adolescents (Yamato et al., 2018). These data reinforce the concept that low back pain is more common among school-age children than previously believed (Calvo-Munoz et al., 2013). Thus, back pain is evidenced as a health problem in school-age children. In this regard, the sedentary lifestyle is possibly one of the most important factors in determining back pain in school-age children (Matlabi et al., 2014). In fact, a sedentary lifestyle, combined with a lack of physical activity, effectively contributes to a lower muscle tone in the back. Some previous studies (Lasota, 2014) have shown that an individual with back pain in adolescence is more likely to develop low back pain in adulthood or that heavy backpacks can cause muscle problems in the neck, shoulders and back, such as scoliosis. In addition, reports of low back pain during adolescence indicate that such pain may represent a risk factor in terms of becoming a pathology in adulthood (Calvo-Munoz et al., 2013; Skaggs et al., 2006).

Despite a lack of evidence regarding some aspects, it is agreed that the transport of backpacks induces several kinematic and kinetic adaptations in posture and gait. Children have been observed to walk at a lower cadence when carrying their school load (Ahmad et al., 2019); (Hong et al., 2000) had already noted such adaptations when observing that 10-year-old children carried at least 20% of their body weight, and Liew et al. (Liew et al., 2016) documented a decrease in stride length but also an increase in walking pace.

Changes in the position of the head and trunk are two common adaptations when carrying excessive weight. When backpacks were loaded at 15% of body weight, significant changes occurred in head angle (reduction of craniovertebral angle or increase in anterior head position) (Chansirinukor et al., 2001; Jones et al., 2009; Jurak et al., 2019). (Mosaad et al., 2015) also observed this change because children aged 8 to 12 years carried at least 7.5% of their body weight; thus, the trunk increased its flexion angle (forward tilt) (Hong et al., 2000; Jones et al., 2009; Liew et al., 2016). It was recommended that future backpack designs included lower loads on the spine because low load placement minimizes the postural adaptations of children on the trunk and head (Jones et al., 2009; Lloyd et al., 2000).

Carrying a backpack can increase reactive forces on the soil and plantar pressure (Ahmad et al., 2019; Hong et al., 2000), and this increase can be conditioned by the child's educational level (Ahmad et al., 2019). The increase in GRF was noted while children carried a backpack weighing only 7.5% of their body weight (Mosaad et al., 2015). Thus, the increased GRF may be responsible for the higher level of knee flexion observed at further distances and may be a strategy to compensate for the inability of the ankle dorsiflexors to attenuate the impact forces (Simpson et al., 2012). In fact, such protective behaviour, when carrying a backpack, can generate smaller relative magnitudes of impact and propulsive forces when compared to the ‘no-load’ condition (Castro et al., 2013). The changes in walking speed and double support time described above could be used to not only maintain stability but also assist in shock absorption (Simpson et al., 2012).

When carrying a backpack on a single shoulder, despite changes induced in the posture (Pascoe et al., 1997), the body adapts to the asymmetric placement of the load, finding a new dynamic balance that is not significantly different compared with the use of two handles (Rodrigues et al., 2018). These adaptations cancel out a possible increase in the loading rate, even in children with scoliosis (Gelalis et al., 2012).

The analysis of GRF based on backpack use is of substantial importance because high levels of GRF are commonly associated with several health problems, such as lower limb injuries (Brzek et al., 2017), degradation of articular cartilage and injuries at the spine level (Kim et al., 2008). Mechanical forces influence spinal growth (Gelalis et al., 2012), and high loading rates can negatively affect bone health (Chen et al., 2018; Voloshin, 2000; Zadpoor et al., 2011). These potential influences have gained emphasis because it is children of growing age who primarily use backpacks on a daily basis.

New approaches to the problem

It is a serious issue for children to be carrying excessive weight in their backpacks. Alternatives have appeared in order to minimize the effects of transporting heavy backpacks, and several models have been proposed. For example, 'BackTpack' places the load bilaterally on the user, with two large pockets at the hip. An analysis of this model demonstrated that although not equal to the 'no load' condition, the displacement of the 'BackTpack' load allowed users to maintain a more upright posture than the traditional backpack — the trunk was more upright, and the distance from the head ahead was decreased; hence, this backpack appears to be a viable alternative. However, this model did not show differences in GRF levels compared to traditional backpacks.

A reduction in forward tilt was also noted (Kim et al., 2008) when testing a backpack model with rigid straps. This model is similar to a traditional backpack, except for the straps, which are used to provide flexibility (Mallakzadeh et al., 2016). Kim et al. (Kim et al., 2008) also described changes in head posture when carrying a double front/rear package (two similar packages, one at the rear of the trunk and the other anteriorly) and when carrying a modified double package (smaller anterior package at the chest level). The double pack was found to promote neck hyperextension when compared to the 'no load' condition, but the modified double pack had a positive influence, minimizing postural deviation by decreasing the anterior angle and the anterior distance of the head when compared to carrying a control backpack (Kim et al., 2008). These kinematic advantages of the anterior/posterior system in terms of head angle and forward tilt decreases may be responsible for the differences noted in anteroposterior GRF levels, which involved a decrease in the need for anteroposterior propulsive force, when compared to a traditional backpack (Lloyd et al., 2000). Ramadan et al. (Ramadan et al., 2013) created a pack, similar to a life jacket, with a large pocket on the back and two small pockets on the chest. A lower level of muscle activity (abdominal and erector spine) was noted as well as less increase in heart rate and increased perception of comfort for all transported load levels.

Ren et al. (Ren et al., 2005) used level walking computer simulations to study the effect of a suspension backpack model. This analysis included linear elastic and linear damping components. The research was conducted based on adults and military material. The authors' calculations suggested that the decrease in suspension stiffness might offer biomechanical advantages, namely the decrease in GRF peak values. Rome et al. (Rome et al., 2006) further showed that the use of elastic ropes to suspend the load of a backpack structure reduced its vertical movement and, consequently, the vertical force on the conveyor; energy expenditure was also decreased when walking with the backpack. This result corroborates the previous suggestion that due to the load phase delay, backpacks with suspended loads can reduce muscle energy expenditure during the transition from single to double support modes (Xu et al., 2009).

Suggestions for further research

Despite attempts to create alternative backpack models, which can offer biomechanical and energetic advantages, it is not common for students to use any of these models. This issue is most likely related to the new models' differences compared to the classic models or because none of these models have aroused commercial interest. Therefore, it is critical to develop effective solutions that would not substantially modify the design of the traditional backpack and that could still bring biomechanical advantages; in particular, new model designs should favourably influence GRF in order to minimize the potential adverse effects described earlier in this review. However, to achieve this aim, it is necessary to determine the characteristics of the cargo typically carried by students. It would, therefore, be interesting to understand the impact of that same load on the GRF, and based on these data, seek a solution that can offer advantages to students without substantially modifying the design and appearance of the traditional backpack.

Chapter 3. Experimental Studies

Study 2

Schoolbag weight carriage in Portuguese children and adolescents: a cross-sectional study comparing possible influencing factors

Abstract

Background. Schoolbags and the consequences of carrying them, particularly those associated with overload, are often studied as a health concern. Modifications in gait and posture were reported when children carried loads that corresponded to more than 10% of their body weight (BW). The aims of this study were to verify the load that is carried by Portuguese students and how it is influenced by factors such as school grade, school schedule, lunch site, physical education, sex and body mass index (BMI). Acquiring a more specific knowledge of the Portuguese context and understanding the influence of these factors may allow us to generate proposals to control them in ways that benefit students. ***Methods.*** The load carried by students in the 5th grade (10.6 ± 0.4years) and 9th grade (14.7 ± 0.6 years) were weighed with a luggage scale on all days of the week, resulting in 680 evaluations. Data related to the school day were also collected, such as the student's lunch site, how he or she got to school and his or her school schedule for that day. Individual height and weight were also assessed. ***Results.*** The 5th grade students carried greater loads than the 9th grade students, resulting in a substantial difference relative to their BW. The school loads of the 5th grade students were mostly greater than 10% of their BWs. Girls tended to carry heavier loads than boys, and overweight students also tended to carry heavier loads. Students who could eat lunch at home carried less weight, and on physical education days, the total load carried increased, but the backpacks of the 5th grade students were lighter. ***Conclusions.*** The results of the current study describe excessive schoolbag weight among Portuguese students and expound on some of the factors that influence it, which can help researchers and professionals design a solution to decrease children's schoolbag loads.

Key Words: Load carriage, Backpack, Children, School, Physical education

Introduction

The carriage of heavy schoolbags by children is a concern (Jayaratne et al., 2012; Rose et al., 2016) for all those involved in student education, health and well-being. Backpacks are the most commonly used type of bag, and overweight backpacks are associated with several health issues, including increased spinal curvatures (Chow et al., 2005; Lai et al., 2001), discomfort and back and shoulder pain (Dockrell et al., 2015; Grimmer et al., 2000; Mackenzie et al., 2003; Mwaka et al., 2014). Some of these health issues, such as back pain during childhood and adolescence, have implications in later life and are predictors of back pain in adulthood (Brattberg, 2004; Hestbaek et al., 2006). Therefore, in addition to its effects on health and quality of life, schoolbag weight is an economic concern and should be considered because back pain is an expensive global problem (Maniadakis et al., 2000).

Changes in gait patterns and posture modifications have been reported when children carry a load that corresponds to more than 10% of their body weight (BW) (Chow et al., 2005; Hong et al., 2000); however, modifications in neck position or in ground reaction forces may occur even when children carry less weight (Mosaad et al., 2015). Brackley et al. (Brackley et al., 2004) concluded that a guideline weight limit of 10–15% BW was justified based on physiological factors, such as the maximum rate of oxygen consumption, energy expenditure, blood pressure or tidal ventilation. Although the scientific community has not reached a universally accepted weight limit proposal, 10% of the BW is the most frequent recommendation (Al-Hazzaa, 2006; Chow et al., 2005; Dockrell et al., 2013, 2015; Lai et al., 2001; Mackenzie et al., 2003; Mosaad et al., 2015; White et al., 2007); nonetheless, this limit is often exceed (Al-Hazzaa, 2006; Goodgold et al., 2002; Jayaratne et al., 2012; Negrini et al., 1999). Therefore, backpack suggestions for better load distribution (Brackley et al., 2009) were made, alternative designs have been proposed (Dahl et al., 2016; Mackenzie et al., 2003; Mackie et al., 2003; Mallakzadeh et al., 2016; Ramadan et al., 2013) and several initiatives have been launched around the world by governments, associations and schools to minimize the unhealthy consequences of carrying heavy schoolbags (Jayaratne et al., 2012; Mackenzie et al., 2003) and to identify strategies to decrease children's exposure to heavy backpacks (Haig et al., 2006).

Additionally, several factors have been associated with load carried, such as age (Whittfield et al., 2001), sex (Dianat et al., 2013; White et al., 2007) and BMI (Dockrell et al., 2015). In New Zealand, younger student (third form) were identified as carrying heavier loads, 7.0 kg (13.2% BW), than the 6.3 kg (10.3% BW) carried by the sixth form primary school finalists, aged approximately 11 years ($p < 0.001$) (Whittfield et al., 2001). Female students from 5th to 12th grades, carried heavier loads, 6.2kg (11.3% BW), than male students, 5.8kg (9.9% BW) in Northern California ($p<0.001$) (White et al., 2007). Overweight students carried heavier loads (5.0 kg) than the normal weight students (4.7 kg), aged 9 to 11 years in Ireland ($p = 0.034$)

(Dockrell et al., 2015). In search of evidence pertaining to the schoolbag load among Portuguese children and adolescents, the aim of current study is to analyse the loads carried by students in the 5th and 9th grades in Portugal. A secondary aim is to understand the impact sex, age, the lunch site and physical education class on school load so that we can better understand how to control those factors for the benefit of the students.

Materials and methods

Participants

This was a cross-sectional descriptive study involving 145 male (48.3%) and female students (51.7%) enrolled in the 5th (10.6 ± 0.4 years) and 9th grades (14.7 ± 0.6 years) at the same public school, in Guarda, Portugal. The 5th grade represents the first year of second cycle and the 9th grade the last year of basic education, according to the education system in Portugal. All the school students at those two levels were considered for the study. Students in a non-regular school program and those in situation that could affect the schoolbag content were excluded from the analysis. The 5th grade male students had a mean weight of 41.2 ± 11.9 kg and a mean height of 145.9 ± 8.0 cm, and the female students had a mean weight of 42.7 ± 11.6 kg and a mean height of 145.0 ± 6.5 cm. The 9th grade male students had a mean weight of 60.7 ± 11.4 kg and a mean height of 166.0 ± 7.6 cm, whereas the female students had a mean weight of 51.8 ± 7.8 kg and a mean height of 157.9 ± 5.8 cm. Most of the school students lived in an urban area (78%), and they travelled to school primarily by car (37%) or by foot (29%), while the remaining 34% of the students travelled to school by bus. Approximately two thirds of the 5th grade students (66%) and 72% of the 9th grade students had a “normal weight” based on body mass index (BMI) calculation.

Procedure

The load carried by each student was measured five times, once per day, during each of the five weekdays. All 680 assessments were performed in the morning (08:40 a.m. - 12:00 pm). The sessions occurred in the student’s classroom during February 2013. A digital scale (SilverCrest IAN 71380) with a 0.05-kg gradation was used to weigh the bags. If the students had more than one bag, such as a sports bag, the additional load was also weighed, and the type of bag was recorded. The lunch spot, residence and the mean of transportation to school were recorded, whereas information about the number of classes was collected in school services. The subject’s heights and weights were determined to the 0.5 cm and 0.5 kg using a Jofre® scale+stadiometer (Jofre, Braga, Portugal) at the beginning of their physical education class while they were dressed in sports clothes and were not wearing footwear. When on the scale+stadiometer, they remained with both feet together, arms and hands along the body and looking ahead.

Data analysis

Non-parametric tests were conducted once not every variable presented a normal distribution, verified by the Kolmogorov-Smirnov test. Comparisons between genders, school years, lunch sites, afternoons without classes, BMIs or physical education days were performed using an independent-samples Kruskal-Wallis test. Spearman's rho test was used to determine the relationship between the load and the number of classes in predominantly theoretical classes and all classes. These procedures and the descriptive statistics were performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY). Statistical significance was set at $p < 0.05$. Cohen's d calculation was performed to calculate the effect size (ES) based on mean differences. Assuming Cohen's d original interval interpretation, the effects could be small (values until 0.2), medium (values of 0.8) and large (values equal and greater than 0.8) (Durlak, 2009). Microsoft Excel (Microsoft Office 365 ProPlus) was used for this calculation and the computation of some variables, such as the maximum load carried by the subjects; the total load, which means the load carried in the backpack plus the load of the extra bag; and the BMI calculation. BMIs were calculated as the ratio of body mass by stature squared and their classification was made using the Centers for Disease Control and Prevention method, available on the institution's website on Microsoft Excel spreadsheet format (Centers for Disease Control and Prevention, 2010), which implies a cut-off to overweight children on percentile 85th. Classes of languages, mathematics, sciences, history and geography were considered as mainly theoretical and physical education, music education, informatics, visual education, technological education and civic education as not mainly theoretical classes.

Results

Considering the maximum load by each subject, 83% of the younger students carried a load greater than 10% of their BW, and 66% carried a load greater than 15% of their BW. When total load is considered, 70% of the students carried more than 15% of their BW, as shown in Table 1.

Table 1. Load carriage by intervals of less than 10%, 10% to 15%, 15% to 20% and more than 20% of the BW by all subjects and only normal BMI subjects [n (%)]; maximum subject's load refers to the highest load carried during the week and all measurements to the mean load carried during the week,

	Maximum subject's load				**All measurements**			
			Normal BMI				Normal BMI	
	Backpack	Total load	Backpack	Total load	Backpack	Total load	Backpack	Total load
5th year								
≤10%	10 (17%)	5 (9%)	1 (3%)	0 (0%)	78 (29%)	60 (22%)	16 (9%)	11 (6%)
>10% & ≤15%	10 (17%)	12 (21%)	4 (11%)	2 (6%)	106 (39%)	103 (38%)	77 (46%)	65 (39%)
>15% & ≤20%	29 (50%)	20 (34%)	22 (61%)	16 (44%)	75 (27%)	81 (30%)	63 (37%)	68 (40%)
>20%	9 (16%)	21 (36%)	9 (25%)	18 (50%)	13 (5%)	28 (10%)	13 (8%)	25 (15%)
9th year								
≤10%	32 (55%)	26 (45%)	19 (49%)	14 (36%)	233 (82%)	213 (75%)	149 (78%)	135 (70%)
>10% & ≤15%	23 (40%)	23 (40%)	17 (44%)	17 (44%)	48 (17%)	56 (20%)	39 (20%)	42 (22%)
>15% & ≤20%	3 (5%)	9 (15%)	3 (8%)	8 (20%)	4 (1%)	16 (5%)	4 (2%)	15 (8%)
>20%	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Also on Table 1, analysing only the subjects with a normal BMI, 97% of the 5th grade students carried a backpack weighing more than 10% of their body weight at least one time per week, and 86% carried a backpack weighing more than 15% of their BW. When the extra bag was included, every 5th student with a normal BMI carried a load greater than 10% of their BW at least once a week. The 9th grade students carried much lighter loads; however, approximately 50% of these students still carried more than 10% of their BW at least once per week. No one carried more than 20% of their BW. When all 5 weekdays and not just the heaviest one were analysed, in 71% of the measurements, the 5th grade students carried a backpack weighing more than 10% of their BW, and in 32% of the cases, their backpack weighed more than 15% of their BW. When extra items carried were considered, the values increased to 78 and 40%, respectively. Analysing only the subjects with a normal BMI, in more than 90% of the cases, these ten-year-old students carried a backpack weighing more than 10% of their BW, and in approximately half of the cases, they carried a backpack weighing more than 15% of their BW. The 9th grade students still carried relatively less weight; only in 18% of the cases did they carry a backpack weighing more than 10% of their BW. 1.

Younger and older students

The 5th grade students carried greater loads in their backpacks than did the 9th grade students (ES(load) = 0.70), which represented a substantial difference in the relative body weight carried (ES(load.BW^{-1}) = 1.42). This situation was still observed when we considered the total load carried; that is, the weight of the backpack plus an extra bag, when present (ES(load) = 0.66 and ES(load.BW^{-1}) = 1.35). When considering only the mean of maximum load that each subject carried during the week, the differences became even more pronounced for both backpack (ES(load) = 0.93; ES(load.BW^{-1})1.61) and the total load (ES(load) = 0.85; ES(load.BW^{-1}) = 1.51) (Table 2).

Table 2. Mean, standard deviation and p-value of the difference between school grades of backpack and total load, in absolute values and after normalizing for body weight.

	Backpack		Total load	
	load (Kg)	load.BW^{-1}	load (Kg)	Load.BW^{-1}
Load (mean)				
5th year	4.99 (1.42)	0.130 (0.044)	5.40 (1.54)	0.140 (0.048)
9th year	4.06 (1.21)	0.078 (0.027)	4.41 (1.44)	0.085 (0.032)
p	<0.001	<0.001	<0.001	<0.001
Max subject's load (mean)				
5th year	6.25 (1.30)	0.160 (0.047)	6.83 (1.30)	0.177 (0.052)
9th year	5.13 (1.13)	0.098 (0.029)	5.69 (1.36)	0.111 (0.034)
p	<0.001	<0.001	<0.001	<0.001

p = level of significance

Number of classes

Table 3 shows that the loads carried to school were directly associated with the number of classes scheduled for the day. Predominantly theoretical classes had a stronger association with load, particularly with backpack weight (Table 3).**Table 3.** Correlation between the load carried and the number of different disciplines per day.

		Backpack		Total load	
		load (Kg)	load.BW^{-1}	load (Kg)	Load.BW^{-1}
Correlation coefficient					
5th year					
	Number of disciplines	0.396	0.281	0.478	0.358
	p	<0.001	<0.001	<0.001	<0.001
	N theoretical disciplines	0.523	0.416	0.439	0.352
	p	<0.001	<0.001	<0.001	<0.001
9th year					
	Number of disciplines	0.196	0.204	0.266	0.290
	p	<0.001	<0.001	<0.001	<0.001
	N theoretical disciplines	0.391	0.348	0.347	0.366
	p	<0.001	<0.001	<0.001	<0.001

Gender, lunch, BMI and physical education

The girls tended to carry heavier loads than the boys. The difference became significant for the 9th grade students backpack (ES(load) = 0.45; ES(load.BW− 1) = 0.91) and total load (ES(load) = 0.39; ES(load.BW− 1) = 0.77). About the 5th grade students, the difference between female and male was significant only on total load (ES(load) = 0.19). A similar result was observed for BMI, as overweight students tended to carry greater loads, and the difference also became significant for the 9th grade students (ES(load) = 0.25). On physical education days, the 5th grade student's backpacks were lighter (ES(load) = 0.40), but the total load carried increased (ES(load) = 0.25). This increase was also observed among the 9th grade students (ES(load) = 0.73). Students who lived near the school and had lunch at home carried less weight (ES(load) = 0.87) (Table 4).

Table 4. Mean, standard deviation and p-value of backpack and total load expressing in kilograms and normalizing for body mass by gender, physical education participation, BMI, afternoon with classes and lunch spot.

	Backpack				**Total load**			
	5th year		9th year		5th year		9th year	
	Load (Kg)	Load.BW^{-1}	Load (Kg)	Load.BW^{-1}	Load (Kg)	Load.BW^{-1}	Load (Kg)	Load.BW^{-1}
Sex								
M	4.87 (1.42)	0.129 (0.046)	3.75 (1.25)	0.064 (0.022)	5.27 (1.57)	0.139 (0.050)	4.08 (1.47)	0.072 (0.027)
F	5.13 (1.42)	0.131 (0.042)	4.29 (1.13)	0.087 (0.026)	5.56 (1.48)	0.141 (0.046)	4.64 (1.39)	0.095 (0.032)
p	0.064	0.546	<0.001	<0.001	0.040	0.513	<0.001	<0.001
BMI								
Normal	5.05 (1.28)		4.09 (1.14)		5.45 (1.37)		4.46 (1.43)	
Overw.	5.19 (1.50)		4.48 (1.25)		5.66 (1.67)		4.86 (1.43)	
p	0.730		0.027		0.467		0.044	
Physical Education day								
Yes	4.63 (1.12)	0.123 (0.037)	4.00 (1.25)	0.080 (0.026)	5.64 (1.42)	0.148 (0.047)	4.83 (1.64)	0.097 (0.035)
No	5.20 (1.55)	0.134 (0.048)	4.10 (1.19)	0.076 (0.028)	5.26 (1.59)	0.136 (0.049)	4.14 (1.23)	0.077 (0.028)
p	0.003	0.057	0.651	0.163	0.018	0.061	<0.001	<0.001
Afternoon with classes								
Yes	5.39 (1.49)	0.132 (0.046)	4.13 (1.24)	0.080 (0.028)	5.87 (1.50)	0.153 (0.049)	4.56 (1.49)	0.089 (0.034)
No	4.33 (1.02)	0.114 (0.036)	3.80 (1.07)	0.069 (0.021)	4.64 (1.26)	0.120 (0.040)	3.82 (1.07)	0.069 (0.021)
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lunch								
Home	4.31 (1.03)	0.112 (0.035)	3.60 (1.04)	0.065 (0.019)	4.63 (1.23)	0.120 (0.040)	3.70 (1.04)	0.068 (0.020)
School	5.25 (1.48)	0.137 (0.046)	4.38 (1.22)	0.084 (0.028)	5.69 (1.55)	0.149 (0.050)	4.90 (1.48)	0.094 (0.034)
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

p = level of significance

Extra bag

Extra bags were used primarily on physical education days. Approximately 90% of the occasions on which the 5th grade students carried an extra bag were physical education days. They carried the extra bag on 86% of the days that they had physical education classes. A sport bag was the most frequently used type of bag, and the mean weight was 1.2 kg (3.2% of BW). Similarly, the 9th grade students almost exclusively used an extra bag when they had physical education (96% of times), but they used it only approximately half of the times they had the class (56%). These students also mainly used a sports bag with a mean weight of 1.5 kg (2.9% of BW).

Discussion

The present study aimed to investigate the loads that Portuguese children in their first (5th grade) and last (9th grade) years of basic school carry to school and to determine the factors that influence those loads. In the present study, the younger students were naturally smaller and lighter, but they carried more weight than the 9th grade students. This caused a substantial difference in the relative weight carried by the students at different ages. The results obtained for the 5th grade students were very similar to those reported in Ireland (Dockrell et al., 2015), particularly in terms of backpack weight, and in Florida (United States of America) (Bryant et al., 2014) and were much lower than the results described for Italian students (Negrini et al., 1999). However, the 5th grade students exceed the published weight limit recommendations of 10% of BW more than 70% of the time, or almost 80% when we considered the total load carried (backpacks and extra bags). Students in Malta (Spiteri et al., 2017) and Ireland (Dockrell et al., 2015) also exceed this recommendation more than 70% of the time. Approximately two-thirds of the children carried a load greater than 15% of their BW at least once a week. When only children with a normal BMI were considered, all the 5th grade students carried more than 10% of their BW at least once a week, and half of them carried more than 20% of their BW. These results suggest that a 10% BW limit does not have any meaning in this 5th grade context. In contrast, the older students, in 9th grade, usually carried loads below 10% of their BW, although half of them exceeded this limit at least once a week.

Girls tended to carry more weight than boys. This tendency has also been reported in the literature (Dianat et al., 2013; White et al., 2007); however, the differences were not always significant (Bryant et al., 2014; Goodgold et al., 2002; Pau et al., 2010; Whittfield et al., 2001). Additionally, in the present study, the sex-specific differences in the absolute and relative weights carried were only consistently significant for the 9th grade students. The same results were observed for BMI, with a tendency for overweight/obese children to carry greater loads that became significant for the 9th grade students. This trend was also verified in another European survey (Dockrell et al., 2015).

Students who lived near the school and were able to eat lunch at home, they preferred to carry only the materials they need for morning classes and exchange them at the lunch time for the items they would need for the afternoon. This was an option for lightening the backpack load, even if it meant spending more time carrying the backpack/load.

All students had afternoons without classes (two in the 5th grade and one in the 9th grade) on their schedules. On those days, the students carried less weight because they normally had fewer classes. As described above, the number of classes was highly associated with the weight carried. In such cases, the use of digital material such as e-books or the adoption of exercise books that could remain at home while the main book stays at school could make a great contribution to relieving students backpack loads.

Physical education days tended to decrease the backpack load but increase the total load. On the one hand, from a weight-management perspective, the advantage here is that the physical education load is carried in an extra bag that can be stored in a locker (if available) or classroom and transported to the sport gym alone, without a backpack. This use of a separate bag promotes the separation of the load, except for travel to and from school, and at least affords protection against shoulder discomfort (Dockrell et al., 2015). On the other hand, the asymmetrical load imposed by a sports bag could produce a spine-tilt effect; however, the very low bag weight used by our students compared with others (Dockrell et al., 2015) is probably not sufficient to cause spine tilt (Hong et al., 2011). Nonetheless, it may be interesting to study other possible effects on gait caused by transporting this extra bag.

Specifically in terms of low back pain, the implications of carrying a heavy backpack are still not agreed upon among the scientific community (Yamato et al., 2018). However, because back pain in childhood and adolescence might have implications on later life (Brattberg, 2004; Hestbaek et al., 2006), all parties should be safe and minimize children's exposure to heavy loads. In this way, we may reduce the risk of certain health issues, such as increased spinal curvatures (Chow et al., 2005; Lai et al., 2001), discomfort (Dockrell et al., 2015; Grimmer et al., 2000; Mackenzie et al., 2003; Mwaka et al., 2014) and modifications on posture (Brzek et al., 2017). Parents should guide students and supervise their school backpack content. It is imperative that schools and book publishers develop a strategy so that children are not forced to transport unnecessary books to and from school each day. For instance, exercise books, which usually remain at home, may be structured to allow students to review the contents without bringing the main book home; additionally, the use of e-books provides an alternative to reduce the load carried by children. Moreover, organizing the weekly school schedule by holding approximately the same number of classes each day, avoiding days with only theoretical classes, and providing lockers where students can store their sports equipment will equalize daily loads and facilitate load management.

The present analysis is based on the data of students who follow the national curriculum at a public school, but it might be affected by the specific conditions of the school and the city where it is located. Thus, generalization to all Portuguese students should take these restrictions into account. For future studies, it is of relevant interest to investigate how the loads carried by children affect ground reaction forces and to determine how carrying sports bags affects both support ground reaction forces and all body movement, perhaps by analysing asymmetrical displacement. Longitudinal studies that investigate the cumulative effects of carrying a schoolbag over several years, as already proposed (Dockrell et al., 2013), could help to clarify the effects on musculoskeletal disorders that are only perceived later on life.

Conclusions

These students generally carried school loads greater than 15% of their BW at least once a week. The situation was more serious for the younger students, who had a lighter BW but carried more weight than the older students. It is important to remember that about 30% of the children go to school walking. The impact of several factors on the school loads carriage were assessed which can help researchers and professionals to design a solution to decrease children's schoolbag loads.

Study 3

Effects of backpacks on ground reaction forces in children of different age during walking, running and jumping

Abstract

Backpacks for transporting school loads are heavily utilized by children and their mechanical advantages have been allowing children to transport heavy loads. These heavy loads may increase ground reaction forces (GRF), which can have a negative effect on joints and bone health. The aim of this study was to investigate the effect of backpacks on the GRF generated by children during walking, running and jumping. Twenty-one children from the fifth (G-5) and ninth (G-9) grades, walked, ran and jumped over a force plate. When walking, the G-5 had GRF increments in the first (17.3%; $p < 0.001$) and second (15.4%; $p < 0.001$) peak magnitude, and in total integral of vertical force (20%; $p<0.001$), compared to the control condition (i.e., no backpack), and the G-9 had increments of 10.4%, 9% and 9% ($p < 0.001$), respectively. The G-9 did not prolong their total stance time ($p>0.05$), unlike the G-5 ($p = 0.001$). When running, total stance time increased 15% ($p < 0.001$) and 8.5% ($p < 0.001$) proportionally to the relative load carried, in the G-5 and G-9, respectively. Peak GRF did not increase in any group when running or landing from a jump over an obstacle. It was found that GRF was affected by the backpack load when walking. When running, schoolchildren prolonged the stance phase, and when landing from a jump, smoothed the landing by prolonging the reception time, thus avoiding GRF peak magnitudes increasing.

Key words: Backpack; Children; Load-carriage; Gait; Ground-reaction-forces.

Introduction

The backpack is the most common strategy adopted by students to carry their school loads (Chow et al., 2010). Its use is widespread because it offers several ergonomic and comfort advantages, such as carrying the load near the trunk, which could be symmetrically distributed and leaves hands free. However, the use of backpacks with heavy loads may induce several modifications in posture and gait, such as reduced pelvic rotation, increments in head angle, a forward head position and trunk flexion (Birrell et al., 2010; Brackley et al., 2009; Castro et al., 2013; Castro et al., 2015; Chansirinukor et al., 2001; Chow et al., 2005; Hong et al., 2003; Kim et al., 2008; Knapik et al., 1996; Pascoe et al., 1997; Quesada et al., 2000; Song et al., 2014). This may lead to adverse effects such as increments in compression of intervertebral disks and in spine curvatures (Chiang et al., 2006; Chow et al., 2010; Grimmer et al., 2000; Haselgrove et al., 2008; Hong et al., 2011; Neuschwander et al., 2010; Pau et al., 2011; Sheir-Neiss et al., 2003).

The use of backpacks may also increase ground reaction forces (GRFs), changing level walking and stair gait patterns (Birrell et al., 2007; Castro et al., 2013; Chen et al., 2018; Mosaad et al., 2015; Simpson et al., 2012). In this way, high GRFs have been associated with injuries at the spine level (Voloshin, 2000) and with lower-limb injuries (Birrell et al., 2007), inducing degradation of the biomechanical properties of the joint cartilage. Mechanical forces influence vertebral growth (Gelalis et al., 2012) and high loading rates may have negative effects on bone health (Duyar, 2008; Zadpoor et al., 2011). In this sense, growing children who use backpacks daily may be at risk, especially if they carry an excessive load, which is the norm (Barbosa et al., 2019; Dockrell et al., 2015; Whittfield et al., 2001).

The scientific community recommends a backpack weight limit of 10% of the child's body weight (BW) (Al-Hazzaa, 2006; Dockrell et al., 2013; White et al., 2007). However, this limit is often exceeded. For example, a recent study found that approximately two-thirds of the Portuguese children analysed, 10 and 15 years of age, carried loads greater than 15% of their body weight at least once a week (Barbosa et al., 2019). Similar results were found by Brzek and colleagues (Brzek et al., 2017) in children from 7 to 9 years old in Poland. This becomes even more disturbing when we realize that younger children carry more weight than the older ones. Studies showed that 10-years-old students carried more weight than the 15 years old students (Barbosa et al., 2019), or that students from grades 5 to 8 (ages 8-13) carried more relative weight than those from grades 9 to 12 (ages 13-18) (White et al., 2007). These loads used by young children, at least until 9 years old, can increase the risk of modifications of posture (Brzek et al., 2017), potentially risking later back pain and/or other health-related issues. Although the scientific literature on this subject is increasing, investigations should be deepened to further understand the effects of improper use of the backpack. In this way, it has already been suggested that research must understand the influence of the loads carried by children of different ages on GRF and all body movement (Barbosa et al., 2019).

To our knowledge, previous studies focusing on studying the loads carried by children have been relying on questionnaires to assess pain variables or measuring the effects of hypothetically backpack loads (Brackley et al., 2009; Chow et al., 2010; Quesada et al., 2000; Sheir-Neiss et al., 2003; White et al., 2007). To improve our knowledge on this issue, we thought important to better understand the effects when using real loads. Therefore, we previously measured the loads carried by the students for a whole week (Barbosa et al., 2019), and characterized the backpack weight used by those children that attended the fifth (10 years old) and the ninth grades (15 years old). Backpack load is not the same across the school years (Barbosa et al., 2019; Brzek et al., 2017) and children's physical features also become different as they grow. That is why we considered it important to analyse these two different school grades. The values obtained were normalized to BW and may be used as a reference for the same population, allowing us to further explore other effects, such as the GRFs with a backpack load from a real context.

The few studies that investigate the influence of the carried load on GRFs, have focused on walking or stair walking (Castro et al., 2013; Keller et al., 1996; Mosaad et al., 2015; Song et al., 2014). Nevertheless, children, especially younger children, also play with their backpack on, including running and jumping. Since these are very different kinds of displacements, what would the effect be of backpack transportation on GRFs during these activities? It is commonly known that vertical GRF peaks increase about twice (Keller et al., 1996) when running or reach 10 times the BW (Ortega et al., 2010) when landing from a jump. Therefore, will backpack transportation increase this even more? Knowing that high GRFs levels could potentially develop adverse health issues (Knapik et al., 1996; Mosaad et al., 2015; Zadpoor et al., 2011), it is important to understand if they are increased by the loads carried by children in their usual activities. Therefore, the aim of this study is to analyse the effect of backpack transportation on GRFs in children during walking, running and jumping, in two different school years.

Material and methods

Participants

Twenty-one children participated in this study, considering the possibility of the school timetable and personal availability. The participants attended the nineth grade (G-9; five females with mean age of 14.82 ± 0.23 years, 55.20 ± 7.09 kg of body mass, 1.57 ± 0.06 m of height, and 22.54 ± 3.20 kg/m2 of body mass index; and seven males with mean age of 15.16

± 0.97 years, 57.71 ± 14.69 kg of body mass, 1.67 ± 0.09 m of height, and 20.52 ± 3.92 kg/m2 of body mass index) and the fifth grade (G-5; four females with mean age of 11.08 ± 0.40 years, 34.25 ± 5.38 kg of body mass, 1.40 ± 0.08 m of height, and 17.70 ± 4.65 kg/m2 of body mass index; and five males, with a mean age of 10.88 ± 0.33 years, 36.20 ± 9.18 kg of body mass, 1.42 ± 0.06 m of height, and 17.68 ± 3.27 kg/m2 of body mass index).

According to the classification of the education system of the country, the fifth grade represents the first year of the second cycle of the basic education system and the ninth grade represents the last year of the third cycle and the last year of basic education. Students in a non-regular school programme and others in a situation that could affect the backpack content were excluded from the analysis.

All children and parents/guardians were informed about the experimental procedures of the study, and after acceptance, the parents/guardians signed the informed consent. This study was conducted in accordance with the International Charter for Ethical Research Involving Children. The data collection was approved by the school principal and the Research Centre in Sports Sciences, Health Sciences, and Human Development at the University of Beira Interior Review Board approved study procedures, in accordance with the Declaration of Helsinki.

Data collection

The experimental sessions took place in the sports equipment storage room of the school sports gym. This room was spacious enough to install all the apparatus, had natural light, and offered privacy, avoiding external influences. Each participant performed the assessments in a single session, so all the tasks could be performed in the same conditions (temperature: 20.8 ± 0.6 ◦C humidity: 54.0% ± 2.0%).

Participants were asked to perform all the evaluations on a wood platform, with 580 cm length, 62 cm width, and 6 cm height. A force plate (MuscleLab, Ergotest Innovation; Porsgrunn, Norway), with 80 cm length, was embedded in the middle of the wood platform. The software "Ergotest MuscleLab" V8.0 (Ergotest Innovation A.S., Porsgrunn, Norway) was linked to the force platform in order to collect and export data. Considering that the purpose was to analyse the effect of the backpack on GRF, both conditions (loaded and unloaded) were performed so they could be compared. All the participants were requested to perform the tests with their usual clothes and shoes, that is, what they wear when carrying their backpack to school. They presented themselves with varied clothes, but all used sports shoes.

At the beginning of each session, participants were asked to walk, run, and jump over the platform to familiarize themselves with the equipment, until they demonstrated similar performance on the platform as they did on the ground. All participants stepped on the force plate with the right foot (dominant) during their walking and running performance. Therefore, they were asked to set their individual starting point so they could walk and run normally and with no need to adjust the movement to step on the GRF platform with the right foot. Subsequently, to familiarize themselves with the jumping task, they jumped with both feet over a cardboard box (23 cm height, 38 cm length, and 51 cm width), landing on the GRF platform several times. All these preparation tasks were done with and without a backpack. Then, the participants rested for 45 min, so that any fatigue effect could be avoided.

The loads carried on the backpack were the mean loads usually carried by these children for each of the school years, as previously reported (Barbosa et al., 2019). The backpack was carried with 5 kg of books by G-5 children and with 4.5 kg by the G-9 children. It was placed over both shoulders and individually adjusted. Adjustment backpack straps were loosened, and the participants were asked to adjust them as they usually do with their backpacks. The backpack used in this study was the Padded model, from the brand "Eastpack" (Boston, MA, USA), one of the most used models by children in the region where the study was conducted.

To avoid learning or fatigue effect, the order of task performance was totally randomized using the "randbetween" function on Microsoft Excel. Each task was evaluated for five repetitions. 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. As the performance order was totally randomized, the first participant could perform his five repetitions of "walk with backpack"; the second "run unloaded"; and the third "jump loaded", for example. Then, a new cycle started, until all tasks were performed by all participants. No performance feedback was provided to the participants during the recording trials.

Data Analysis

Microsoft Excel (Microsoft Office 365 ProPlus) was used to randomize conditions of performance order with the randbetween function and to organize data exported from MuscleLab. The variables analysed 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). Magnitudes of force variables were also calculated in the function of the BW of the subjects. The relative effect of the backpack (BPackW) was calculated by dividing the difference between loaded and unloaded by the backpack weight. Figure 1 can be observed as a typical force/time curve obtained during data collection in walking and running situations.

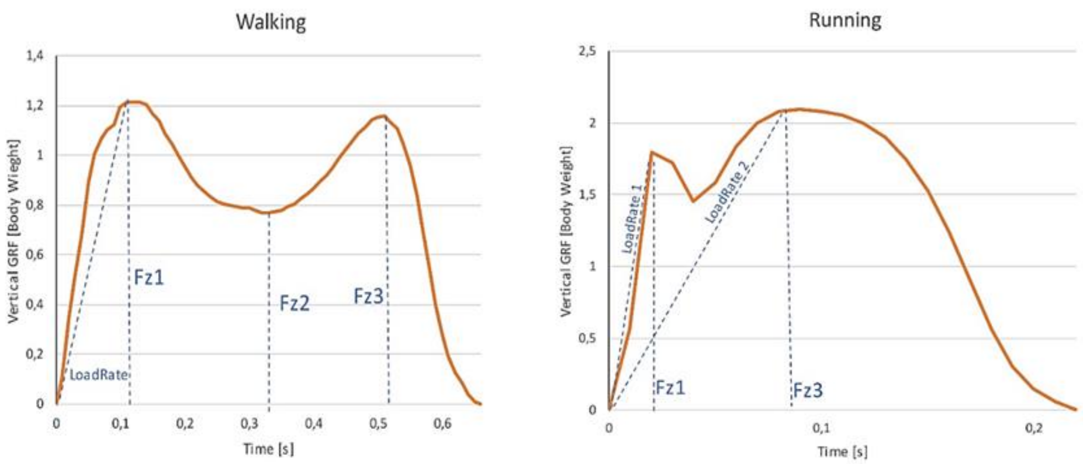

Figure 1. Typical vertical ground force (GRF)/time curves from one of the participants during unloaded walking and running, demonstrating the first peak (impact force peak - Fz1), relative minimum (Fz2), the second peak (Fz3) and the loading rate (LoadRate), normalized to body weight.

To analyse data results, descriptive statistics, the T-Test for paired samples, the T-Test for independent samples, normality tests, and intraclass correlation coefficient were performed. As the main goal was to compare the tasks performed with and without a backpack on each subject, the T-Test for paired samples was the main statistical operation. The T-Test for independent samples was used only to compare the relative effect of the backpack between G-5 and G-9 on the walking GRF peaks.

Statistical procedures were performed using the Statistical Package for the Social Sciences (SPSS v.20) (IBM, Corp., New York, USA), and the statistical significance was set at $p < 0.05$. 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 (Faul et al., 2007). As originally proposed by Cohen (Cohen, 1988), the interpretation of the effect sizes was considered small when $0.2 \leq d < 0.5$; medium when $0.5 \leq d < 0.8$; and large when $d > 0.8$.

Results

Good-to-excellent inter-trial repeatability was found for all variables (Intra-class correlation coefficient > 0.90) on the walking and running situations. When walking, the loads that students usually carry to school increased stance time and deeply affected all force variables analysed. In the G-5, the first peak magnitude increased 17.3%, the second peak magnitude increased 15.4%, and the relative minimum increased 14% with the backpack on. The total integral of vertical force increased by 20%. The rate of increasing the vertical force from the first touch on the ground until the first peak increased by 11.1%. In this group, the total stance time increased mainly by time between peaks, and probably with higher importance of the first half, which is the time between the first peak until reaching the minimum value of vertical force (Table 1).

Older students (G-9) carried less weight, specifically about 8% of the BW. There were no significant differences in the time variables between the use or non-use of a backpack. However, as with younger students, the presence of the load on the backpack increased all force variables. The first peak increased by 10.4%, and the second peak was incremented at 9%. On the contrary, the increment on the relative minimum was only 3%, which represents only 28% of the added load. The total integral of forces increased by 9%. The loading rate until the first peak was incremented on 360 N/s (7.2%) (Table 1).

When running with a backpack on, stance time increased 15% in fifth-grade students and 8.5% in ninth-grade students. Force variables were affected differently than in walking: peak values were not increased, and the rate of force applied decreased. Only the integral of force increased—14% and 9%—yet less than when walking (Table 2).

When landing from jumping over the obstacle with both feet at the same time, the integral of force increased for both; however, remaining variables were affected distinctly in fifth-grade students and in ninth-grade students: no differences were observed in fifth-grade students, while in ninth-grade students, the landing time increased, and force peak decreased (Table 3).

Table 1. Time and force variables (mean ± standard deviations) for loaded and unloaded walking.

Walking	G-5				G-9			
	Unloaded	Loaded	*p*	*d*	Unloaded	Loaded	*p*	*d*
Time variables								
Total stance time (s)	0.61 ± 0.06	0.63 ± 0.05	0.001	0.55	0.65 ± 0.04	0.66 ± 0.04	0.077	
Time to Fz1(s)	0.13 ± 0.02	0.14 ± 0.02	0.188		0.14 ± 0.05	0.14 ± 0.01	1.000	
Time from Fz1 to Fz2 (s)	0.16 ± 0.03	0.17 ± 0.02	0.088		0.16 ± 0.07	0.17 ± 0.02	0.391	
Time from Fz2 to Fz3 (s)	0.18 ± 0.03	0.178 ± 0.05	0.696		0.18 ± 0.03	0.18 ± 0.02	0.925	
Time after Fz3 (s)	0.15 ± 0.02	0.15 ± 0.02	0.161		0.17 ± 0.03	0.17 ± 0.02	0.855	
Time between peaks (s)	0.33 ± 0.04	0.34 ± 0.04	0.009	0.40	0.34 ± 0.08	0.35 ± 0.02	0.437	
Force variables								
First peak-Fz1 (N)	433.01± 108.29	507.98 ± 130.27	<0.001	1.50	695.74 ± 128.03	768.37 ± 150.18	<0.001	1.14
First peak-Fz1 ($N.BW^{-1}$)	1.24 ± 0.11	1.46 ± 0.14	<0.001	1.62	1.26 ± 0.14	1.39 ± 0.16	<0.001	1.19
Fz1 BPackW ($N.BW^{-1}$)		1.53 ± 1.26				1.65 ± 1.45	0.030#	
Fz2 (N)	217.99 ± 51.87	248.56 ± 44.67	<0.001	0.78	379.96 ± 86.17	392.07 ± 89.62	0.049	0.26
Fz2 ($N.BW^{-1}$)	0.63 ± 0.10	0.73 ± 0.13	<0.001	0.89	0.68 ± 0.08	0.71 ± 0.09	0.022	0.30
Second peak-Fz3 (N)	417.39 ± 63.57	481.65 ± 94.61	<0.001	1.25	650.18 ± 116.30	708.46 ± 131.45	<0.001	1.27
Second peak-Fz3 ($N.BW^{-1}$)	1.22 ± 0.10	1.40 ± 0.10	<0.001	1.52	1.18 ± 0.07	1.28 ± 0.09	<0.001	1.34
Fz3 BPackW ($N.BW^{-1}$)		1.31 ± 0.16				1.32 ± 0.13		
MaxAbsl (N)	446.06 ± 98.22	520.92 ± 125.04	<0.001	1.79	709.81 ± 122.55	774.42 ± 145.19	<0.001	1.07
MaxRelative ($N.BW^{-1}$)	1.29 ± 0.10	1.50 ± 0.11	<0.001	2.33	1.3 ± 0.16	1.42 ± 0.19	<0.001	1.11
Total integral (N.s)	167.79 ± 37.35	201.06 ± 43.95	<0.001	2.64	289.4 ± 62.75	314.86 ± 66.83	<0.001	1.37
LoadRate ($kN.s^{-1}$)	3.42 ± 1.05	3.80 ± 1.12	0.023	0.35	5.00 ± 0.98	5.36 ± 1.05	0.017	0.32

BPackW = (loaded − unloaded)/backpack weight; (N/BW) = normalized to bodyweight. Fz1 = first vertical force peak; Fz2 = vertical force relative minimum; Fz3 = second vertical force peak; MaxAbsl = vertical force absolute maximum; # p level for the comparison between G-5 and G-9; p = level of significance; d = effect size.

Table 2. Time and force variables (mean ± standard deviations) for loaded and unloaded running.

Running	G-5 Unloaded	Loaded	*p*	*d*	G-9 Unloaded	Loaded	*p*	*d*
Time variables								
Total stance time (s)	0.26 ± 0.03	0.30 ± 0.03	<0.001	1.61	0.30 ± 0.03	0.32 ± 0.03	<0.001	0.94
Time to Fz1 (s)	0.03 ± 0.01	0.04 ± 0.01	0.017	0.37	0.04 ± 0.01	0.04 ± 0.01	0.056	
Time to Fz2 (s)	0.11 ± 0.02	0.13 ± 0.02	<0.001	0.74	0.12 ± 0.02	0.14 ± 0.02	<0.001	0.76
Time between peaks (s)	0.08 ± 0.01	0.09 ± 0.02	0.001	0.55	0.09 ± 0.01	0.10 ± 0.02	<0.001	0.66
Force variables								
First peak-Fz1 (N)	502.77 ± 191.88	486.97 ± 152.16	0.416		729.75 ± 210.28	729.3 ± 219.93	0.984	
First peak-Fz1 ($N.BW^{-1}$)	1.46 ± 0.43	1.41 ± 0.34	0.444		1.36 ± 0.32	1.35 ± 0.28	0.811	
Second peak-Fz2 (N)	854.61 ± 159.96	835.51 ± 170.55	0.105		1395.71 ± 263.7	1405.72 ± 290.71	0.396	
Second peak-Fz2 ($N.BW^{-1}$)	2.49 ± 0.19	2.42 ± 0.18	0.051		2.63 ± 0.52	2.64 ± 0.48	0.723	
MaxAbsl (N)	854.61 ± 159.96	835.9 ± 170.03	0.110		1395.71 ± 263.7	1405.72 ± 290.71	0.396	
Max Relative ($N.BW^{-1}$)	2.44 ± 0.19	2.37 ± 0.17	0.054		2.58 ± 0.51	2.59 ± 0.47	0.726	
Load Rate 1 ($kN.s^{-1}$)	16.85 ± 10.25	14.51 ± 7.41	0.058		23.35 ± 10.85	20.78 ± 7.28	0.019	0.31
Load Rate 2 ($kN.s^{-1}$)	7.71 ± 1.34	6.76 ± 1.68	<0.001	0.56	11.51 ± 2.76	10.59 ± 2.84	<0.001	0.53
Total integral (N.s)	113.83 ± 31.05	129.99 ± 30.34	<0.001	1.68	203.32 ± 41.29	222.22 ± 44.77	<0.001	1.26

BPackW = (loaded − unloaded)/backpack weight; (N/BW) = normalized to bodyweight. Fz1 = first vertical force peak; Fz2 = vertical force relative minimum; Fz3 = second vertical force peak; MaxAbsl = vertical force absolute maximum; # p level for the comparison between G-5 and G-9; p = level of significance; d = effect size.

Table 3. Time and force variables (mean ± standard deviations) for loaded and non-loaded jumping

Jumping	G-5 Unloaded	Loaded	*p*	*d*	G-9 Unloaded	Loaded	*p*	*d*
Time variables								
Total reception time (s)	0.24 ± 0.16	0.29 ± 0.19	0.102		0.34 ± 0.17	0.42 ± 0.139	0.000	0.49
Time to max (s)	0.04 ± 0.02	0.04 ± 0.02	0.847		0.06 ± 0.02	0.061 ± 0.02	0.050	0.26
Force variables								
MaxAbsl (N)	1783.90 ± 580.90	1761.40 ± 627.50	0.786		2474.50 ± 804.30	2269.20 ± 659.40	0.011	0.34
Max Relative ($N.BW^{-1}$)	5.14 ± 1.37	5.05 ± 1.43	0.699		4.49 ± 1.24	4.12 ± 1.00	0.011	0.34
LoadRate ($kN.s^{-1}$)	61.25 ± 42.34	61.68 ± 39.52	0.944		58.26 ± 49.05	46.69 ± 40.57	0.072	
Total integral (N.s)	144.25 ± 92.60	178.52 ± 104.08	0.025	0.34	308.97 ± 149.92	387.96 ± 138.61	0.000	0.62

N.BW−1 = normalized to bodyweight. MaxAbsl = vertical force absolute maximum; p = level of significance; d = effect size.

Discussion

The current study aimed to investigate the influence of the load carried in school backpacks on GRFs. It was our intention to analyse real daily conditions – that is, to analyse the impact of loads that child carry to school in a real context. The loads carried had been previously assessed, and thus we could use the loads that are normally carried by children who were attending 5th grade and 9th grade at a public basic school (Barbosa et al., 2019). It was found that generally, carrying these loads affected GRFs when walking and running. When walking, the peak values of each phase of support, integral of forces and loading rate were increased with a backpack on, in both groups. However, these force variables were affected differently in running. In this situation, the peak values were not increased, and the rate of force decreased for both groups. When landing from jumping, the integral force was increased for both groups, but the landing time increased and force peak decreased only on 9th grade students.

The findings were consistent with several other studies that compared unloaded with loaded walking (Ahmad et al., 2019; Birrell et al., 2007; Castro et al., 2013; Chow et al., 2005; Liew et al., 2016; Mosaad et al., 2015; Razali et al., 2006; Simpson et al., 2012). To our knowledge, no studies have done this analysis on another mean of locomotion beyond walking. The studies reported walking speed decreases (Castro et al., 2013; Chow et al., 2005), increased magnitudes of vertical GRF (Birrell et al., 2007; Mosaad et al., 2015; Simpson et al., 2012) and a protective behaviour by the loaded participants (Castro et al., 2013; Simpson et al., 2012) in order to attenuate the increments of the vertical GRF magnitudes. In this investigation, we found these previously reported effects, but they were expressed differently based on the student's school level and types of locomotion.

When walking, the use of a backpack by 5th grade students induced a prolongation of the stance time, which is in line with the data recorded by Ahmad and colleagues (2019), when 7-9-year-old children carried a backpack. We also registered a great increment of the force peaks and the integral of forces when backpack was carried. The first peak magnitude increased by 17%, and the second peak increased 15% in the G-5. Mosaad and colleagues (2015) registered an increment of 11% of the first peak by 10-year-old children when carrying 7.5% of their BW. It should be noted that the children in the current study carried about 14.3% of their BW. Razali and colleagues (2006) registered increments of 10.4% and 25% when children of 9 to 10 years of age carried the backpacks with 10% and 15% of their BW, respectively. Despite the high increase in first peak force magnitude, the loading rate increased only 11% which means a lower increment. This could indicate an adaptation on the first phase of the stance, like differences in the ankle and/or knee angles. That could only be clarified with a kinematics complementary analysis. As observed by Simpson and colleagues (2012), with increased load, children unconsciously adjust gait features, namely, the speed and the knee flexion. This attenuation could be framed as a protective behaviour, adapting the gait pattern in consequence of load carriage, and aiming to minimize possible harmful effects of high vertical GRFs over the musculoskeletal system, as suggested by Castro and colleagues (2013). The total integral influenced both by the increment in force peaks and the prolongation of the stance increased 20% with the backpack on in the G-5 when walking.

The 9th grade students did not prolong their stance time in the walking situation. However, they also had large increments in the first and second force peaks. The 10% increment of the first peak could be compared to the 11% increment verified by Mosaad and colleagues (2015), as reported above, with the children carrying a similar relative load. While unloaded, the magnitude of the first peak was about 1.25 BW for every student, which is in an expected range of values (Keller et al., 1996). However, when backpack is added, the magnitude of the first peak increased by a factor of 1.5 (G-5) or 1.6 times (G-9) the load added. Therefore, the load added in the backpack had the double of the influence than if that load was added as BW. That means that the magnitude of the first force peak of a 50kg student with a backpack of 5kg should be higher than that of a 55kg student. This is probably due to the modifications caused by posture and gait patterns (Mosaad et al., 2015), as the backpack is not fully attached to the body. Accordingly, the first force peak of G-5 could be calculated through the formula 1.25xBW+1.53xBackpackWeight and, in the case of G-9, the formula should be 1.26xBW+1.65xBackpackWeight. Applying this analysis to the data provided by Mosaad and colleagues (2015), where 10-year-old children carrying 7.5% BW were studied, we obtain the formula 1.12xBW+1.60xBackpackWeight. Therefore, similar levels of the relative effect of the backpack were found on the first peak of GRF.

Curiously, as it is possible to ascertain above, the influence of the backpack on the first peak was higher on G-9 (measured as the percentage of change). As G-5 carried a greater relative load, they had the need to slow down the displacement, more so than the G-9, which is in agreement with previous studies where greater relative loads induced greater decreases in walking speed and increases in support time (Ahmad et al., 2019; Chow et al., 2005). For example, Ahmad and colleagues (2019) found significant and moderate main effects of the load on the velocity and duration of the stance, for loads of 10% BW and 15% BW on children of 7-9 years old. Therefore, as higher speeds lead to higher GRF peaks values increments (Keller et al., 1996; Schwartz et al., 2008), this could explain the greater relative influence of the backpack among G-9. Following this analysis, in the second peak, the factor of increment was about 1.3 times the load added, for both groups. In this case, the walking speed had no influence, as expected. According to Schwartz and colleagues (2008), walking speed affects the first peak more than it affects the second peak.

Comparing again to the data provided by Mosaad and colleagues (2015), the increment in the second peak was also 1.3 times the load added. So, the relative influence of the backpack load was very similar than that found in this study, especially on G-9. Remember that children carried 7.5% of their BW, close to our G-9 (8% of BW). This may indicate the possibility of predicting the effect on GRF peaks by knowing the backpack load, at least on the situations framed on the “comfort zone”, where children don’t need to adjust gait features.

If, when walking, all force variables increased with added load, when running the findings were different. Peak forces did not increase, and the loading rate 2 decreased. This is probably due to the significant decrease verified in speed, evidenced by the increment in stance time. However, about the loading rate 1, the difference was not significant in the G-5 and the difference in time was not significant in G-9. The time to reach the first peak was about 0.03 and 0.04 seconds. So, being a very quick event, maybe the low frequency of our force platform (100 Hz) didn’t allow to identify the exact moment of this peak. Therefore, extra variability could be introduced on the data, conditioning the statistics.

When running, G-5 increased the stance time in about 15% of unloaded condition, while G-9 increased by about 8% the unloaded time. Interestingly, there were similar values of the relative load carried what may suggest that children had the need to slow down the movement on the same proportion of the load carried. Silder and colleagues (2015) verified a smaller increase in the standing time, but also verified an increase in vertical GRF peak in adult runners wearing a weight vest. In the present study, children prolonged their stance in order to totally avoid the GRF increment, evidencing the protective effect described by Castro and colleagues (2013) for walking or simply to contain the backpack’s oscillation. When running, because it’s not fully attached, the backpack tends to maintain a desynchronized movement with the body.

When the children were jumping over a paper box with both feet at the same time, the backpack induced obviously visible modifications to the movement. The increment on the knee flexion was obvious and originated a 20% prolonged reception so they can keep GRF magnitudes acceptable.

Some limitations of the current study should be addressed, in addition to the already identified low frequency of the force platform. We acknowledge that this study was performed for students who follow a specific national curriculum at a public school, and the results might be affected by the specific conditions of the school, city, and country. The current data should be interpreted within the context of the study and its sample of young students. The primary limitation of this research is the limited number of subjects. There are inherent difficulties in randomizing some individuals when attempting to investigate young students at a public school. Because of the small sample size, we tried to understand the effects of using a backpack in males and females together. In this way, we increased the statistical power of the data results, and consequently, it was possible to obtain more reliable conclusions. We should not disregard the possible existence of different maturational status of females or/and males, mainly in G-9. This is usually a confounding factor in research, but in this specific case, it was not considered relevant. According to the main purpose of the study, we performed a within-subject analysis. This meant that each subject was compared with himself or herself, regardless of maturational status, and/or sex, removing any possible influence of these factors.

Future studies should increase the number of participants and analyse different ages and maturational statuses. This would allow us to deepen the analysis of the data. Moreover, studies should also look further into the physiological response of carrying a backpack and should try to find strategies (i.e., by changing the design of the backpack) to reduce the impact of carrying it.

Conclusions

The loads carried by the Portuguese students in their backpacks significantly affected GRFs. When walking, the load carried induced significant increments in GRF peaks and integral of force, with superior effect sizes on the fifth-grade children. In both groups, the increment in GRF peak magnitude was more than 1.5 times the load added (or 150% of the load added). When running, load-bearing students increased stance time on the proportion of the relative load carried, avoiding GRF peak magnitude increases. School children also succeeded in avoiding GRF peak magnitudes increase when landing from a jump with the backpack, smoothing the landing by prolonging the reception time by about 20%.

Study 4

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

Abstract

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. Nine children (5 boys and 4 girls) were included in the group G-5 (age: 11.0 ± 0.3 years-old; body mass: 35.3 ± 7.3 kg; height: 1.41 ± 0.1 m) and twelve (7 boys and 5 girls) in G-9 (age: 15.0 ± 0.7 years-old; body mass: 56.7 ± 11.2 kg; height: 1.63 ± 0.1 m). Participants attended a single session and were initially asked to walk and then to run over a force plate. The software Ergotest MuscleLab v8.0 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. 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. 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.

Key words: Backpacks, modified straps, ground reaction forces, locomotion.

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 (Chow et al., 2010; Dockrell et al., 2013). The literature on the topic has raised concerns about heavy loads carried in the backpacks by children (Barbosa et al., 2019; Brzek et al., 2017; Hestbaek et al., 2006), some relating them to health issues (Chow et al., 2010; Neuschwander et al., 2010; Pau et al., 2011). However, most of the concerns are associated with the effect of the backpack load on posture and gait patterns, such as reduced pelvic rotation (Chow et al., 2005); increments on the angle of the head (an adopted forward position) (Hong & Cheung, 2003; Kim et al., 2008; Song et al., 2014); excessive trunk flexion (Chow et al., 2005; Hong et al., 2003; Kim et al., 2008; Song et al., 2014); and an increase in ground reaction forces (GRF) (Castro et al., 2013; Castro et al., 2015; Chen et al., 2018; Simpson et al., 2012). These heavy backpacks may cause the above mentioned postural changes (Barbosa et al., 2019). 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.

The mechanical forces influence vertebral growth (Gelalis et al., 2012), and high loading rates may have negative effects on bone health (Zadpoor et al., 2011). For instance, growing children who use backpacks daily may suffer high GRF level associated with lower-limb (Birrell et al., 2010; Hong et al., 2005) and spinal injuries (Voloshin, 2000). This leads to a health-related problem as already presented in literature (Perrone et al., 2018). That may be explained by children's motor activities, such as running or jumping while carrying school backpacks (Keller et al., 1996). Efforts have been made to define a load limit to be carried (Dockrell et al., 2013; Lindstrom-Hazel, 2009), which is most frequently set at 10% of the child's body weight (BW) (Al-Hazzaa, 2006; Dockrell et al., 2013; Xu et al., 2009). However, this limit is often exceeded (Al-Hazzaa, 2006; Brattberg, 2004; Hestbaek et al., 2006). 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 (Barbosa et al., 2019; Brzek et al., 2017).

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 (Dahl et al., 2016) or replacing the flexible shoulder straps by rigid ones (Mallakzadeh et al., 2016). 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 (Kim et al., 2008), and the abdominals and spinal erectors muscular activity (Ramadan et al., 2013). As mentioned before, the load stress is typically measured by the GRF. In an attempt to reduce the GRF peak values, Ren et al. (Ren et al., 2005), 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 (Ren et al., 2005). 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 (Barbosa et al., 2019; Brzek et al., 2017) 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 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.

Material and methods

Participants

Twenty-one 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. Nine children (5 boys and 4 girls) were included in G-5 (age: 11.0 ± 0.3 years-old; body mass: 35.3 ± 7.3 kg; height: 1.41 ± 0.1 m) and twelve (7 boys and 5 girls) in G-9 (age: 15.0 ± 0.7 years-old; body mass: 56.7 ± 11.2 kg; height: 1.63 ± 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).

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: 580 cm; width: 62cm; high: 6cm). 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, Boston, USA), and the backpack was modified by introducing elastics in the strap shoulders (Figure 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.

Figure 2. The modified tested backpack prototype

The weight carried in the backpack was the average loads usually carried by the participants according to the school year, as reported elsewhere (Barbosa et al., 2019). 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.

Data Analysis

Microsoft Excel (Microsoft Office 365 ProPlus) was used to randomize the performance order conditions and to organize data exported from MuscleLab. The analysed variables analysed 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 (Barbosa, et al., 2019).

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). 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 (Faul et al., 2007). As originally proposed by Cohen (1988), 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.

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 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).

Table 1. Time (t) in seconds (s) 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	0.330		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; MaxAbsl = vertical force absolute maximum; Diff. max-min = difference of magnitude between the absolute maximum and the minimum between peaks; *p* = level of significance; d = effect size.

Table 2. Time and force variables (mean ± standard deviations) for running with traditional backpack and 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.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 ($N.BW^{-1}$)	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 ($N.BW^{-1}$)	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	0.13	
LRate to first peak ($kN.s^{-1}$)	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	
LRate second peak ($kN.s^{-1}$)	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	

Fz1 = first vertical force peak; Fz2 = vertical force relative minimum; Fz3 = second vertical force peak; Max = maximum; LRate = loading rate; *p* = level of significance; d = effect size.

Regarding the comparison between males and females, table 3 presents the differences between the backpacks for boys and girls when walking. The table 4 presents the comparison when running. For the walking condition, only significant differences were observed for t to Fz1 (s) for girls (Δ = -0.008; p =

0.010; d = 0.34) and boys (Δ = 0.005; p = 0.041; d = 0.25). The load rate presented significant differences for girls (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 boys.

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	0.82		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 ($N.BW^{-1}$)	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 ($N.BW^{-1}$)	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 ($N.BW^{-1}$)	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 ($N.BW^{-1}$)	1.40 ± 0.1	1.39 ± 0.13	0.75		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 ($kN.s^{-1}$)	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	0.95	
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	

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.

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.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 ($N.BW^{-1}$)	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 ($N.BW^{-1}$)	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 ($kN.s^{-1}$)	19.20 ± 9.17	17.29 ± 7.48	0.055		17.19 ± 6.92	16.44 ± 6.94	0.303	
LoadRate second peak ($kN.s^{-1}$)	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

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/dissipation effect, reducing the GRF peak magnitudes. 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 (Barbosa et al., 2019). 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 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 material on the shoulder straps (Xu et al., 2009) 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 of the center of gravity, originated by the propulsion force produced in this phase, forcing the elastic to elongate.. 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 force from the first peak to the following moments. This may be seen as a small phase delay of the load due to the elastic straps, similar to another study with a suspended-load backpack (Foissac et al., 2009); 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 (Barbosa et al., 2019). This may speculate that the straps will allow the decrease of the integral force for each locomotion type. Moreover, the same study (Barbosa et al., 2019) 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 (Barbosa et al., 2019). However, the magnitude of the effects was different in the present study with straps compared with different loads (Barbosa et al., 2019). 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 (Barbosa et al., 2019; Silder et al., 2015). 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 (Foissac et al., 2009).

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 (Silder et al., 2015). 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. (Ren et al., 2005), 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 (Barbosa et al., 2019).

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 (McKay et al., 2005). 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 attached 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.

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.

Chapter 4. General Discussion

The purpose of the current investigation was to improve the understanding of school backpacks problem and to contribute to a solution. In three different phases, the aims were: first, to characterize the loads that students in Portugal carry on their backpacks; second, understand how those specifically loads affects the ground reaction force (GRF) acting on those students; and third, propose and study modifications on backpack design that can attenuate those effects on GRF.

There is the perception that students carry excessive load to school on their backpacks (Jurak et al., 2019; Perrone et al., 2018). In fact, for example, 80% of children who reported low back pain blamed it on an excessive school backpack weight (Skaggs et al., 2006). However, science has had difficult to define a universal load limit from which it should consider excessive (Chen et al., 2018; Yamato et al., 2018). This difficult may come from the several variables and the multiple approaches that can be taken when analyzing this matter. However, 10% of the student's weight have been the limit more consensual and shared by the World Health Organization (SNS). However, we could conclude, based on studies performed on different countries, from different continents, that students carry more than 10% of their weight (Al-Hazzaa, 2006; Bryant et al., 2014; Brzek et al., 2017; Dockrell et al., 2015; Whittfield et al., 2001). It is possible that much of them achieved to carry more than 30% of their weight, at least once a week (Negrini et al., 1999).

The student age is a factor that influence the relative weight carried (Brzek et al., 2017; Lasota, 2014; Whittfield et al., 2001). Younger children were found to carry more relative weight than older ones. In this regard, the concern about the influence of school backpack load transportation on child health turns more critical.

The results of this thesis confirmed that younger students (5^{th} grade) carried more absolute weight than the older ones (9^{th} grade). Moreover, the younger students were naturally smaller and lighter, what caused a substantial difference in the relative weight carried. The 5^{th} grade students exceed the 10% of body weight (BW) more than 70% of the time, or almost 80% when considering the total load carried (backpacks and extra bags). These results are in line with studies realized on other countries (Bryant et al., 2014; Dockrell et al., 2015; Spiteri et al., 2017). In contrast, the older students, in 9^{th} grade, usually carried loads below 10% of their BW, although half of them exceeded this limit at least once a week.

The transport of backpacks loads above the limit can induces several kinematic and kinetic adaptations in posture and gait. Modifications on walking cadence (Ahmad et al., 2019), stride length (Liew et al., 2016), the head position (Jurak et al., 2019; Liew et al., 2016) and trunk flexion angle (Jones et al., 2009; Liew et al., 2016). Carrying a backpack can also increase GRF magnitudes and plantar pressure (Ahmad et al., 2019; Hong et al., 2000). An increase in GRF was identified while children carried a backpack weighing only 7.5% of their body weight (Mosaad et al., 2015). Some of the identified modifications on walking pattern while carrying a heavy backpack could be protective behaviours to attenuate the increase in GRF magnitudes, like a greater knee flexion and changes in walking speed and double support time (Simpson et al., 2012). The analysis of GRF based on backpack use is of substantial importance because high levels of GRF are commonly associated with several health problems, such as lower limb injuries (Brzek et al., 2017), degradation of articular cartilage and injuries at the spine level (Kim et al., 2008). Mechanical forces influence spinal growth (Gelalis et al., 2012), and high loading rates can negatively affect bone health (Chen et al., 2018; Voloshin, 2000; Zadpoor et al., 2011). Our results confirmed that carrying a school backpack can affect GRF.

It matters to remember that we previously assessed the mean load carried to school by the 5th grade students and 9th grade students, and those were the loads used in the experimental procedures for each group. The 5th grade students, who carried a greater relative load, had bigger effects sizes.

When walking, the use of a backpack by 5th grade students induced a prolongation of the stance time, which is in line with the effects previously observed (Ahmad et al., 2019). We also registered increments of the force peaks and the integral of forces when backpack was carried. The first peak magnitude increased 17%, and the second peak increased 15%, in the G-5. This means an increment of 153% the load added on the first peak and 130% on the second peak. Previously studies recorded similar relative increments (Mosaad et al., 2015; Razali et al., 2006).

Despite the high increase in first peak force magnitude, the loading rate had a lower increment. This may be due to the prolongation of the stance time that attenuated the loading rate increment. As observed by Simpson and colleagues (2012), in consequence of load carriage, children unconsciously adjust gait features, namely, the speed and the knee flexion, aiming to minimize possible harmful effects of high vertical GRFs over the musculoskeletal system, as suggested by Castro and colleagues (2013). The total integral, influenced by the increment in force peaks and by the prolongation of the stance, increased 20% with the backpack on, in the G-5.

The 9th grade students, who carried less relative weight, did not prolong their stance time in the walking situation. Which is in agreement with previous studies, when comparing with G-5, where greater relative loads induced greater decreases in walking speed and increases in support time (Ahmad et al., 2019; Chow et al., 2005). However, they also had large increments in the first and second force peaks. The 10% increment of the first peak could be compared to the 11% increment verified by Mosaad and colleagues (2015), where children carried a similar relative load. In fact, the 9th grade students were carrying less relative weight, they increased the first force peak by 160% the load they were carrying, which was more than the 150% of the G-5. That could be explained by the greater displacement speed of G-9 students, inferred by the shorter stance time, once higher speeds lead to higher GRF peaks values increments (Keller et al., 1996; Schwartz et al., 2008). Following this analysis, in the second peak, the factor of increment was about 1.3 times the load added, for both groups. In this case, the walking speed had no influence, as expected. According to Schwartz and colleagues (2008), walking speed affects the first peak more than it affects the second peak.

For walking, all force variables increased with added load; whereas for running the findings were different. Peak forces did not increase, and the loading rate decreased. This is probably due to the significant decrease verified in speed, evidenced by the increment in stance time, because students increased the stance time on the proportion of the load carried: G-5 increased the stance time in about 15% of unloaded condition, while G-9 increased about 8% the unloaded time. Children prolonged their stance in order to totally avoid the GRF increment, evidencing the protective effect described by Castro and colleagues (2013) for walking, or simply to contain the backpack's oscillation, once when running, because it's not fully attached, the backpack tends to maintain a desynchronized movement with the body. When the children were jumping over a paper box with both feet at the same time, the backpack induced obviously visible modifications to the movement. The increment on the knee flexion was obvious and originated a 20% prolonged reception so they can keep GRF magnitudes acceptable.

In order to sensitize to this possible adverse effects of carrying scholar heavy backpacks, several worldwide initiatives have been taking place (Jayaratne et al., 2012; Mackenzie et al., 2003). Also, several models of backpack have been proposed by the scientific community with the intention of minimize the effects (Dahl et al., 2016; Mackenzie et al., 2003; Mackie et al., 2003; Mallakzadeh et al., 2016; Ramadan et al., 2013). However, these models have designs significantly different from the traditional one, making difficult their adoption by the students (Mackie et al., 2003). So, we made modifications to the original backpack, with the intention of attenuate the GRF magnitudes and loading rates increment and still not significantly change the original design. Those modifications were the introduction of elastic material on the backpack straps. We were theorizing that the elastic could absorb a part of the energy generated by the vertical brake of the stance, dissipating it along the stance time and making possible a lower maximum level of vertical force. Ren et al. (Ren et al., 2005) developed a theoretical model where was suggested that a backpack suspension model with a lower stiffness may offer biomechanical advantages, namely the decrease on the peak values of GRF.

With this proposal we produced changes on GRF magnitudes. Probably the most important, once it was our main goal, was the decrease of the loading rate and force peaks, on some tested conditions, when compared with the non-modified backpack use.

When walking, only G-9 experimented significant differences between the two conditions. We could record a decrease of the first vertical force peak and a decrease of the loading rate. G-5 did not have differences between the two backpacks, probably because the load carried was so high that totally stretched the elastics, leaving no margin so they could actuate. Also, for running, carrying the modified backpack, decreased the peak value of force decreased as well as the loading rate. Even the G-5 experimented differences between the two backpacks, contrary to the walking condition. The greater rebounds of the backpack may explain the differences between conditions. The running probably promoted moments where the elastics could shorten, and then be able to stretch again, absorbing energy.

These results showed that is possible to attenuate the increments on GRF magnitudes and loading rates without significantly modify the backpack design, facilitating its adoption by students. They also may encourage to deeply understand how the advantageous can be controlled and maximized, by adjusting the elastic material stiffness to each student-load specific condition. Still, we think that some procedures and measures are important to concretize, such as to provide lockers to store sports equipment, the supervision of school backpack content by parents and the implementation of strategies by schools and book-publishers to diminish the necessity to transport material to and from school.

Chapter 5. Overall Conclusions

The main findings of this work confirmed that, like it was verified in other countries, students in Portugal carried more weight on their school backpacks than it is recommend and provided more information about the influence of carrying backpack loads in ground reaction force (GRF). Also, it was proposed and studied a mean to limit the influence of the backpack load in GRF by introducing elastic material on backpack straps, with encouraging results. The main specific conclusions of this work were:

i. Scientific community did not yet turn clear the level of influence of carrying backpack heavy loads on children health, but it is considered that it could occur in several body structures like the spine or the lower limbs, affecting the joint cartilage and bone health.

ii. Due to the multiple approaches that can be taken when analysing this matter, scientific community has had difficult to define a universal load limit from which it should be considered excessive. However, 10% of the student's weight have been the limit more consensual and shared by the World Health Organization.

iii. The results of this thesis confirmed that younger students (5^{th} grade) carried more absolute weight than the older ones (9^{th} grade), creating a great difference on the relative load carried.

iv. The 5^{th} grade students exceed the 10% of BW more than 70% of the time, or almost 80% when considering the total load carried (backpacks and extra bags) and carried loads greater than 15% of their BW at least once a week. The older students, in 9th grade, usually carried loads below 10% of their BW, although half of them exceeded this limit at least once a week.

v. The loads carried by the Portuguese students in their backpacks significantly affected GRFs. When walking, the load carried induced increments in GRF peaks and integral of force, with greater influence on the 5^{th} grade children. The increment in GRF peak magnitude was more than 1.5 times the load added (or 150% of the load added).

vi. When running and jumping children increased stance or landing time to avoid GRF peak magnitude increases. When running stance increased on the proportion of the relative load carried, and when landing from a jump with the backpack, the landing time increased 20%.

vii. The introduction of elastic material on the backpack straps produced changes on GRF magnitudes, namely the decrease of the loading rate and force peaks, on some tested conditions, when compared with the non-modified backpack use.

Chapter 6. Suggestions for future investigations

We would like to deeply understand how to control and maximize the advantageous of the elastic introduction on the backpack straps, so we are proposing that theme for future investigation. Understand how the elastic stiffness can be adjusted to the load carried, to the children mass, or probably more efficient, to both.

For this study, 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 attached exclusively by the elastics, promoting a bigger range of motion for the elastics. This idea is probably worth exploring.

Also, how the concept could be applied to sportive backpacks, like hike or trekking backpacks, or if the presence of the hip belt on this type of bags will cancel the elastic effect.

Moreover, we would like to know the influence on GRF of the transport of a common “sport bag”, usually carried on one shoulder with a big strap, so it could be compared with the backpack use.

Finally, a relation between bags weight and the effects on articular cartilages health would be important to assess to define limits of bag’s weight.

Chapter 7. References

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