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Short-term effects of backpack carriage on plantar pressure and gait in schoolchildren

Massimiliano Pau [a,*], Serena Mandaresu [a], Bruno Leban [a], Maury A. Nussbaum [b]

[a] Department of Mechanical, Chemical and Materials Engineering, University of Cagliari, Cagliari, Italy
[b] Department of Industrial & Systems Engineering, Virginia Tech, 521 Whittemore Hall (0118), Blacksburg, VA 24061, USA

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ABSTRACT

Purpose: To assess the effects of backpack carriage on plantar pressure distributions and spatio-temporal gait parameters among children.
Participants: Two hundred-eighteen schoolchildren, aged 6–13, and attending primary and secondary schools in the city of Cagliari (Italy).
Methods: Participants were tested at school, during regular days. A pressure plate and wearable inertial sensors were used to measure plantar pressures and spatio-temporal parameters of gait. Measures were obtained during both quiet standing and walking, and both with and without a backpack. The latter contained those items a child had on the testing day.
Results: Participants carried a mean mass in their backpacks of 5.2 kg, and more than half had a backpack/body mass ratio higher than 15%. While spatio-temporal gait parameters were not affected by backpack carriage, significant increases (up to 25%) in plantar pressures were found during both static standing and walking, especially in the forefoot.
Conclusion: Under realistic conditions, the impact of backpack carriage was more evident on foot-ground interaction than on gait features. However, long-term consequences of altered plantar pressure need to be assessed in future work, considering the actual durations typically spent carrying school items.

1. Introduction

Backpacks represent the most widely used method to carry school items among children and teenagers, with percentages of use reported up to 90% and more (Grimmer and Williams, 2000; Whittfield et al., 2001; Goodgold et al., 2002; Forjuoh et al., 2003; Pau and Pau, 2010). Backpacks may reduce biomechanical/energetic demands (Malhotra and Sen Gupta, 1965; Datta and Ramanathan, 1971; Legg, 1985) and free the upper limbs for other purposes. Nevertheless, there has been grown concern about possible adverse consequences stemming from backpack use, especially related to excessive weight, positioning on the back, and sub-optimal design aspects such as uncomfortable shoulder straps and an absence of waist straps (Hamilton, 2001; Mackie et al., 2003, 2005).

Existing reports have indicated that backpack use may contribute to postural alterations, such as increased trunk forward flexion (as a reaction to the altered position of the center of mass of the 'body plus backpack' system), reduced lumbar lordosis and kyphosis (Bloom and Woodhull-McNeal, 1987; Pascoe et al., 1997; Negrini and Negrini, 2007; Mackie and Legg, 2008; Singh and Koh, 2009), static balance impairments (i.e., increased postural sway, Pau and Pau, 2010), and modifications of the plantar pressure distribution (Pau et al., 2011). Additional effects may include changes in spatio-temporal parameters of gait, such as a reduction of velocity and stride length and an increase of stance and double support phases duration especially when asymmetric carriage is performed (i.e. the backpack is worn using only one strap), though evidence regarding such effects is mixed. Early work by Pascoe et al. (1997), who used 2D video recording to analyze the gait and posture of children aged 11–13 years who carried a 7.7 kg backpack (corresponding to a 17.5% of backpack/body mass ratio), reported a significant reduction in stride length with backpack use, and an increase in stride frequency. Hong and Brueggemann (2000) tested boys, all aged 10, who walked at a fixed speed on a treadmill wearing a backpack loaded to 10–20% of body weight. They found increased durations of stance and double support phase, and decreased swing time, but only for the highest load condition. Similar results were found by Singh and Koh (2009), among students

* Corresponding author at: Department of Mechanical, Chemical and Materials Engineering, University of Cagliari, Piazza d'Armi, 09123 Cagliari, Italy. Tel.: +39 070 6753264; fax: +39 070 6755717.
E-mail address: massimiliano.pau@dimcm.unica.it (M. Pau).

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aged 9, specifically a decrease in gait velocity (but not cadence nor stride length) and an increase in double support time only with a backpack load equal to 20% of body weight.

In contrast to such changes resulting from backpack use, Hong and Cheung (2003) did not find any significant changes in gait parameters (i.e., gait velocity, cadence, stride length, stance and swing phase duration, and single and double support time) in a sample of 9–10 year old children. An absence of changes in stance, swing, single and double support times, or walking velocity and stride time was also found by Devroey et al. (2007) in a cohort of college-aged students using three loading conditions (backpack weights equal to 5%, 10%, and 15% of body weight). Connolly et al. (2008) tested 7th-grade children using the GAITRite® electronic walkway, with a fixed backpack/body weight ratio of 15%, and observed no significant modifications of walking velocity or stride length, though a significant increase in double support time was found.

Moreover, it has been suggested (though this issue is still debated) that backpack use is a factor in the onset of musculoskeletal disorders, particularly low back pain (Grimmer and Williams, 2000; Negrini and Carabalona, 2002; Trevelyan and Legg, 2006). Of note, some of these adverse effects can be exacerbated in obese children (Pau et al., 2012, 2013; De Paula et al., 2012). Considering the increasing trend of childhood obesity worldwide (Wang and Lobstein, 2006), more attention to this issue is warranted to avoid potential negative long-term consequences.

Most experimental studies of backpack use among schoolchildren have been performed in a laboratory setting, often testing relatively small samples. It would be desirable to perform tests directly at school, thereby involving more realistic conditions and making the children more relaxed and comfortable (i.e., enhancing external validity), and with larger samples (enhancing generalizability). Recent developments in wearable and portable sensors provide an opportunity to obtain data on important aspects of human movement (including backpack use), and to do so at reasonable cost outside of a laboratory.

Using such devices (in particular inertial sensors and pressure platforms) this study investigated whether gait alterations existed with the use of backpack in a sample of children and early adolescents. Of particular focus were spatio-temporal gait parameters and plantar pressure patterns. In fact, changes in spatio-temporal parameters may reflect compensatory mechanisms used by children to minimize either an induced gait instability or mechanical strain on the musculoskeletal system (Singh and Koh, 2009). On the other hand, anomalous plantar pressure patterns (i.e. excessive pressure values and/or alterations of the load sharing ratios between the different plantar sub-regions) are a potential source of foot problems, which range from simple foot blisters to more serious metatarsalgia or stress fractures (Knapik et al., 1996). Moreover, it is hypothesized that mechanical overloading on the foot, and the consequent altered plantar pressure distribution, especially in the midfoot region, may contribute to the onset of plantar fasciitis (Wearing et al., 2006).

The current work expanded on prior reports (Pascoe et al., 1997; Hong and Brueggemann, 2000; Hong and Cheung, 2003; Chow et al., 2005; Devroey et al., 2007; Connolly et al., 2008; Singh and Koh, 2009) in using a larger sample size and reproducing more realistic conditions as each participant is tested at school with his/her own backpack loaded as routinely did for a regular day of lessons. Moreover, to the author's knowledge, it is the first to investigate changes in dynamic plantar pressure patterns associated with level walking among schoolchildren who use a backpack. On the basis of the noted considerations, the main purpose of the study was to assess the effects of backpack carriage on plantar pressure magnitudes and distribution, and on spatio-temporal parameters of gait. As a secondary aim of the study, the relationship between carried load and plantar pressure parameters was investigated.

2. Methods

2.1. Participants

In January 2013, the Department of Mechanical, Chemical and Materials Engineering of the University of Cagliari established a collaboration agreement with three primary and secondary schools located in the cities of Cagliari and Elmas (Sardinia, Italy) to investigate gait issues related to backpack use. After discussion and formal approval by the Boards of Management, a total of 623 families were informed through dedicated meetings and by means of a flyer in which purposes and modalities of the experimental tests were explained. Of these, 409 (66%) expressed a willingness to participate and signed an informed consent form.

As the study was focused on backpack carriage, we excluded those children ($n = 191$) who either reported other carriage methods (i.e. trolley or other kinds of bag) or used a backpack only occasionally. Subsequently, the final sample was composed of 218 children aged 6–13 years (109 males and 109 females). At the time of testing (performed in the period March–May 2013) none of the participants had any pathological foot abnormalities, acute/chronic injuries, or other diseases/conditions likely to influence level walking. Summary anthropometric features of the tested children are provided in Table 1.

2.2. Data acquisition and post-processing

To ensure that backpacks were "normally" loaded, data collection was performed at random times on regular school days; the children were aware of the on-going study, but not of the exact date of the test sessions. At the time of data collection, children were called in pairs into a dedicated quiet room with their backpacks loaded with the same items as when they entered school. After shoe removal, stature, body weight, and backpack weight were recorded. Subsequently, static plantar pressure distribution was acquired

Table 1
Anthropometric features of the children in the study. Values are expressed as means (SD).

	Age (years)	Stature (cm)	Body mass (kg)	BMI (kg m^{-2})
Grade 1				
Boys ($n = 14$)	6.8 (0.3)	117.4 (6.9)	23.4 (3.4)	16.9 (1.6)
Girls ($n = 23$)	6.8 (0.4)	116.8 (5.0)	24.0 (4.9)	17.5 (2.7)
Grade 2				
Boys ($n = 17$)	7.8 (0.3)	122.9 (5.8)	26.6 (6.5)	17.4 (3.0)
Girls ($n = 14$)	7.6 (0.3)	125.6 (4.5)	27.6 (3.4)	17.4 (1.7)
Grade 3				
Boys ($n = 7$)	8.8 (0.3)	128.7 (8.6)	30.8 (8.2)	18.5 (3.4)
Girls ($n = 10$)	8.9 (0.3)	127.4 (7.0)	29.2 (6.3)	17.8 (2.8)
Grade 4				
Boys ($n = 19$)	9.7 (0.3)	135.5 (3.9)	36.6 (5.9)	19.9 (2.7)
Girls ($n = 21$)	9.6 (0.3)	134.9 (5.0)	33.5 (7.3)	18.3 (3.1)
Grade 5				
Boys ($n = 16$)	10.9 (0.3)	141.6 (7.4)	39.8 (8.0)	19.7 (2.7)
Girls ($n = 17$)	10.7 (0.4)	142.6 (6.5)	37.4 (5.9)	18.3 (1.8)
Grade 6				
Boys ($n = 15$)	11.4 (0.3)	145.7 (4.9)	39.3 (4.4)	18.6 (2.4)
Girls ($n = 11$)	11.4 (0.3)	143.8 (9.0)	40.2 (11.9)	19.1 (3.6)
Grade 7				
Boys ($n = 8$)	12.2 (0.6)	149.6 (6.8)	41.4 (6.6)	18.6 (3.2)
Girls ($n = 8$)	12.5 (0.3)	150.5 (6.5)	43.2 (11.1)	18.8 (3.3)
Grade 8				
Boys ($n = 13$)	13.4 (0.3)	161.5 (7.3)	52.6 (11.2)	20.0 (2.8)
Girls ($n = 5$)	13.4 (0.2)	157.0 (2.2)	55.2 (4.7)	22.4 (2.5)