Ground reaction forces and plantar pressure distribution during occasional loaded gait

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ABSTRACT

This study compared the ground reaction forces (GRF) and plantar pressures between unloaded and occasional loaded gait. The GRF and plantar pressures of 60 participants were recorded during unloaded gait and occasional loaded gait (wearing a backpack that raised their body mass index to 30); this load criterion was adopted because is considered potentially harmful in permanent loaded gait (obese people). The results indicate an overall increase (absolute values) of GRF and plantar pressures during occasional loaded gait ($p < 0.05$); also, higher normalized (by total weight) values in the medial midfoot
and toes, and lower values in the lateral rearfoot region were observed. During loaded gait the magnitude
of the vertical GRF (impact and thrust maximum) decreased and the shear forces increased more than did the proportion of the load (normalized values). These data suggest a different pattern of GRF and plantar pressure distribution during occasional loaded compared to unloaded gait.

Keywords:
Backpack, Ground reaction forces, Loaded gait, Load carriage, Plantar pressure

1. Introduction

The backpack seems to be an appropriate way to carry load because the load is positioned close to the body's center of gravity while maintaining stability (Chansirinukor et al., 2001; Datta and Ramanathan, 1971; Legg, 1985). It has been widely used for different purposes: students fill backpacks with books and stationery, while hikers and soldiers load them with tents and supplies (Al-Khabbaz et al., 2008). Studies analyzing physiological aspects of load carriage indicate that the energy cost increases progressively with increases in backpack load (Knapik et al., 1996). This is possibly related to changes in the biomechanical aspects of gait. Kinetic analyses found increases in magnitude of vertical and anterior-posterior ground reaction forces (GRF) (Birrell and Haslam, 2010; Birrell et al., 2007; Simpson et al., 2012) and in peak lumbosacral forces (Goh et al., 1998). Kinematic analyses indicate increases in knee range of motion (Attwells et al., 2006; Birrell and Haslam, 2010; Birrell et al., 2007; Simpson et al., 2012) and hip flexion (Attwells et al., 2006; Birrell and Haslam, 2010), while hip abduction and rotation decreases (Birrell and Haslam, 2010). An increased forward lean of the trunk and forward position of the head also was found (Attwells et al., 2006; Chansirinukor et al., 2001; Hong and Cheung, 2003). A longer double support time and duration of stance phase (Birrell and Haslam, 2010) as well as decreased step length (Birrell and Haslam, 2009; Simpson et al., 2012) compared to unloaded gait were evidenced. Increasing load also has been shown to alter lower limb muscle activity (Ghori and Luckwill, 1985; Harman et al., 1992; Simpson et al., 2011a) and rectus abdominal muscle activity (Al-Khabbaz et al., 2008).

The mentioned alterations possibly contribute to a significant association between the backpack weight and occurrence of back pain (Grimmer and Williams, 2000; Skaggs et al., 2006). Simpson et al. (2011b) found loads of 20, 30 and 40% of the body weight inducing significant changes in posture, self-reported exertion and shoulder discomfort in female hikers. Johnson et al. (1995) showed that as load increased, fatigue and muscle discomfort intensified, and alertness and feelings of well-being diminished in military personnel during road marches. A significant relationship between fatigue and back pain was found as well (Negrini et al., 1999). The higher muscular tensions necessary to sustain these charges have also been associated with injury, muscle strain and joint problems (Birrell and Haslam, 2009). Rucksack palsy is another injury related to load carriage (Knapik et al., 1996).

It is common the occurrence of lower limb injuries as a consequence of backpack usage. Carrying heavy loads such as 20 kg seems to contribute to second metatarsal stress fractures (Arndt et al., 2002) and may play a role as a co-factor in plantar fasciitis onset (Wearing et al., 2006). Analyzing strenuous conditions such as walking long distances (20 km) with heavy loads (45 kg), the incidence of metatarsalgia and knee pain were found from 3.3% to 20% and 0.6e15%, respectively (Knapik et al., 1992). The most common load-carriage-related injury is foot blisters (Cooper, 1981; Knapik et al., 1992). Their development is believed to be a consequence of increasing pressure on skin and the creation of more friction between the foot and shoe through higher propulsive and braking forces (Kinoshita, 1985; Knapik et al., 1992). As the abnormal force application over the plantar surface of the foot may be an important factor in the development of many of the mentioned injuries (Arndt et al., 2002; Knapik et al., 1996; Wearing et al., 2006), the knowledge of the GRF and plantar pressure distribution over the foot may help to better understand these pathological conditions as well as to prevent and treat them.

The influence of backpack load on plantar pressure distribution was assessed by Rodrigues et al. (2008) and Pau et al. (2011), who analyzed school children during quiet stance upward position. The former study did not find influence of load (5, 10 and 15% of the body weight) on plantar force distribution, whereas the latter found higher plantar peak pressures in midfoot and rearfoot regions (20e30%) while children carried their own backpacks (not a controlled load). Regarding the influence of carriage load on pressure distribution along the plantar surface on dynamic conditions such as walking, little is known. Studies analyzing gait have been interested only in the GRF. The GRF analysis does not provide information on where the forces are acting on the foot. The combined analysis of the horizontal and vertical GRF and pressure data (distribution of the vertical GRF along the plantar surface) provide more detailed information about characteristics of the forces acting on the human body. Therefore, the aim of the present study was to compare the GRF and plantar pressure parameters between unloaded and loaded gait. These data may help in developing strategies, such as special insole or gait training, to minimize the impact that load carriage seems to have on the locomotor system.

2. Methods

2.1. Participants

A convenience sample of 60 (30 males, 30 females) sport science students (mean age of 23.0 ± 3.7 years old, mean height of 1.68 ± 0.10 m and mean body mass of 67.8 ± 11.2 kg) participated in this study. All were physically active and had body mass indexes (BMIs) lower than 25 kg/m^2. Participants were excluded from this study if they showed any traumatic-orthopedic dysfunction or difficulty with independent gait. This research was approved by a local ethics committee and all participants freely signed an informed consent form, based on the Helsinki declaration, which explained the purpose and the procedures of the study.

2.2. Apparatus

Bertec force plate model 4060-15, operating at 1000 Hz, an amplifier signals system model AM 6300 (Bertec Corporation, Columbus, Ohio, USA), and a Biopac analog-digital converter (BIOPAC System, California, USA) were used to capture GRF. F-Scan in-shoe pressure system (TekScan, South Boston, USA) operating at 300 Hz with about 960 pressure cells, 3.9 sensors/cm^2 and a 0.18 mm thick insole sensor were used to capture plantar pressure data. Three digital cameras were used for visual inspection, if necessary.

2.3. Tasks and procedures

The participants underwent three phases: preparation, familiarization and testing. In the first phase the procedures that would be performed were explained to the participants and their weight and height were recorded. For each participant, the amount of additional weight needed to raise the BMI to 30 kg/m^2 was calculated, and then a backpack was filled with corresponding amount of sand and fixed at the central area of the back. The loads placed inside the backpack ranged from 14.1 to 30.1 kg (mean load 20.3 ± 4.4 kg). For the school children population, 10e15% of the body mass is considered the load limit for the backpack in order to prevent impairment (Lindstrom-Hazel, 2009). Based on changes in muscle activity, posture and self-reported exertion and discomfort, a load limit of 30% of the body mass was suggested for female recreational hikers (Simpson et al., 2011a, b). The traditional methods of load normalization are body mass percentage and fixed load approach. However, for the general adult population, there is not clear what is the load limit for preventing musculoskeletal injury while carrying a backpack. The I Class Obesity (BMI > 30 kg/m^2) is a well documented risk factor for traumatic-orthopedic injuries being considered as possible threshold for such dysfunctions (Ko et al., 2010; WHO, 2000). We would like to assess the effect of a potential harmful load on the musculoskeletal system. Even aware of the differences in body mass distribution and time duration of load (occasional vs. permanent) between obese people and backpackers, we believe that the BMI ¼ 30 kg/m^2 as load criterion may provide the loaded characteristics aimed for the study.

A cuff unit measuring 98 × 64 × 29 mm with Velcro straps was attached on the lateral malleolus region of both legs of each participant: a 9.25 mm cable linked the cuff to the VersaTek hub (F-Scan system), which was connected to a computer. The cable did not cause any restriction of the gait. A pair of thin socks and, aiming to minimize the effects of different soles, neutral shoes (ballet sneakers) with sensor insoles inside was provided for every participant. During the familiarization, the participants walked freely (without backpack) over a 6 m walkway with a force plate embedded in the middle. The researcher identified the starting position for the participant so the right foot would hit the force plate without altering the gait. In the last phase, the participants performed three valid trials without backpack (unload condition, which was called control group e CG) and three with backpack (loaded condition, which was called backpacker's group e BpG). They walked looking forward with a self-selected speed and performed, at least two steps before and after reaching the plate. The trials were considered valid when the subjects reached the plate with the whole foot over it without altering their gait pattern. Alterations in the gait pattern such as step length or pace were assessed subjectively by visual inspection comparing the gait performed during the familiarization time and the trials.

2.4. Data Analysis

The Acknowledge software (BIOPAC System, California, USA) was used to acquire the GRF. The F-Scan Research 6.33 software (TekScan, South Boston, USA) was used to acquire the plantar pressure data. The GRF and plantar pressure data (values of each sensor in each frame) were exported to Matlab 7.0 software (MathWorks, Massachusetts, USA). A program was developed for processing and calculation of the analyzed variables.

All force and pressure variables were shown in absolute values and normalized by the total weight (body mass for CG and body mass plus backpack mass for the BpG), while all time variables were normalized by the stance phase. The systems were synchronized by an external trigger that started them together.

The dependent variables from the GRF data were calculated for absolute ($_{Abs}$) and normalized ($_{Norm}$) values and time ($_{Time}$), respectively, for the following events:

- Impact peak ($PkVt_{I\_Abs}$, $PkVt_{I\_Norm}$ and $PkVt_{I\_Time}$): the highest value of the vertical GRF at the first half of the stance phase (first peak);
- Thrust maximum ($TMVt_{Abs}$, $TMVt_{Norm}$ and $TMVt_{Time}$): the highest value of the vertical GRF found at the second half of the stance phase (second peak);
- Minimum between the peaks (Vt_{Min_Abs}, Vt_{Min_Norm} and Vt_{Min_Time}): minimum value of the vertical GRF between the $PkVt_I$ and TMVt;
- Braking peak ($PkAP_{B\_Abs}$, $PkAP_{B\_Norm}$ and $PkAP_{B\_Time}$): the highest value (negative) of the anterior-posterior GRF at the first half of the stance phase;
- Propulsive peak ($PkAP_{P\_Abs}$, $PkAP_{P\_Norm}$ and $PkAP_{P\_Time}$): the highest value (positive) of the anterior-posterior GRF found at the second half of the stance phase;
- Medial-lateral peak ($PkML_{Abs}$, $PkML_{Norm}$ and $PkML_{Time}$): the highest value of the medial-lateral GRF during the stance phase.

Considering in-shoe pressure data, first the program divided the foot into 10 regions as proposed and adapted from previous studies (Cavanagh and Ulbrecht, 1994; Gurney et al., 2008). The boundary between the rearfoot (RF) and midfoot (MF) was located at 73% of the foot length (from toes to heel). The RF was divided into three equal parts (33% each). The boundary between the MF and forefoot (FF) was located at 45% along the foot length. The MF was divided into two equal parts (50% each). The FF was divided into three regions: 30% medial (first metatarsal region), 25% central (second metatarsal region) and 45% lateral (lateral metatarsals region). The other two regions were the Hallux (Hlx) and lesser toes (Toes) (2nd, 3rd, 4th and 5th toes). The sensor peak (Pk), which was defined as the sensor that presented the highest pressure value, and the time of its occurrence were calculated for every region. The Pk data were calculated to absolute ($_{Abs}$) and normalized ($_{Norm}$) values. Thus, the follow dependent variables were calculated: medial RF ($PkRF_{Med\_Abs}$, $PkRF_{Med\_Norm}$ and $PkRF_{Med\_Time}$); central RF ($PkRF_{Ct\_Abs}$, $PkRF_{Ct\_Norm}$ and $PkRF_{Ct\_Time}$); lateral RF ($PkRF_{Lat\_Abs}$, $PkRF_{Lat\_Norm}$ and $PkRF_{Lat\_Time}$); medial MF ($PkMF_{Med\_Abs}$, $PkMF_{Med\_Norm}$ and $PkMF_{Med\_Time}$); lateral MF ($PkMF_{Lat\_Abs}$, $PkMF_{Lat\_Norm}$ and $PkMF_{Lat\_Time}$); medial FF ($PkFF_{Med\_Abs}$, $PkFF_{Med\_Norm}$ and $PkFF_{Med\_Time}$); central FF ($PkFF_{Ct\_Abs}$, $PkFF_{Ct\_Norm}$ and $PkFF_{Ct\_Time}$); lateral FF ($PkFF_{Lat\_Abs}$, $PkFF_{Lat\_Norm}$ and $PkRF_{Lat\_Time}$); hallux ($PkHlx_{Abs}$, $PkHlx_{Norm}$ and $PkHlx_{Time}$); and lesser toes ($PkToes_{Abs}$, $PkToes_{Norm}$ and $PkToes_{Time}$). The initial and final double limb stance (as percentage of stance phase) was calculated as well. The program automatically divided the plantar regions: all divisions were checked by two trained researchers and, if necessary (eventually), corrected manually.

The in-shoe pressure system presents good information about relative distribution of plantar forces while their absolute values have been questioned (Nicolopoulos et al., 2000; Rosenbaum and Becker, 1997; Woodburn and Helliwell, 1996). The force plate is considered the most accurate dynamic measurements of force (Cobb and Claremont, 1995): thus, the force plate was used to calibrate (post-test) the plantar pressure data test by test.

2.5. Statistical analysis

The intra-individual repeatability for the variables $PkFF_{ct\_Abs}$, $PkRF_{ct\_Abs}$, $PkVt_{I\_Abs}$ and duration of stance phase was verified by means of intra-class correlation coefficient (ICC). The mean of the three trials of each subject was computed and all the statistical procedures were performed with these mean values. The normality of the data was verified by the KolmogoroveSmirnov test and the homogeneity of the variances using Levene's test. Nine out of the 102 sets of value calculated (48 for each group) did not show normal distribution ($PkHlx_{Abs}$ in both groups, $PkRF_{lat\_Abs}$, $PkRF_{ct\_Abs}$ and $PkRF_{med\_Anb}$ in CG, $PkRF_{med\_Abs}$ and $PkToes_{Norm}$ in BpG, and PkML in both groups). The natural logarithmic transformation was done for these variables and the transformed values were used in inferential statistics tests. To compare the variables between the groups (CG vs. BpG), the paired Student's *t*-test was used. The significance level was a ¼ 0.05. The statistical procedures were made using SPSS software (v.17; SPSS Inc, Chicago, IL, USA).

3. Results

An excellent data repeatability was found. The variables $PkFF_{ct\_Abs}$, $PkRF_{ct\_Abs}$, $PkVt_{I\_Abs}$, and duration of stance phase showed ICC of 0.98 ($CI_{95\%}$ 0.97e0.99), 0.97 ($CI_{95\%}$ 0.95e0.98), 0.86 ($CI_{95\%}$ 0.78e0.91) and 0.94 ($CI_{95\%}$ 0.90e0.96), respectively.

The duration of the stance phase and the initial double limb stance were longer during BpG gait compared to CG, while the final double limb stance did not show statistical differences (Table 1).

In the BpG, except for the MF, nine out of 10 plantar regions showed significantly larger absolute pressure values compared to CG (Fig. 1A). The larger sensor peak magnitudes in BpG occurred in Hlx, RF_{Ct} and FF_{Ct} with values of 471.99 ± 260.56 kPa, 419.00 ± 117.25 kPa and 403.26 ± 121.01 kPa, respectively. In the CG they occurred in Hlx, RF_{Ct} and FF_{Lat} with values of 397.39 ± 255.05 kPa, 356.72 ± 108.20 kPa and 335.41 ± 124.15 kPa, respectively. Considering the normalized values, the BpG presented larger values in $PkToes_{\_Norm}$ and MF_{Med_Norm} while lower magnitudes in $PkRF_{Lat\_Norm}$ compared to CG (Fig. 1A). The largest absolute differences occurred in FF_{Med}, RF_{Med} and RF_{Ct}, and the largest normalized differences occurred in Toes, FF_{Med} and Hlx with the BpG showing always higher values compared to CG (Table 2).

In all GRF events the BpG presented significantly larger absolute forces compared to CG (Fig. 1B and Table 2). Considering normalized values, BpG presented higher normalized values for $PkAP_{B\_Norm}$ and lower values for $PkVt_{I\_Norm}$, $PkML_{\_Norm}$ and

Table 1
Mean, standard deviation (SD) and significant level (p) of the stance time variables.

Variables	Control group		Backpacker's group		
	Mean	SD	Mean	SD	p
Duration of stance phase (s)	0.787	0.064	0.813	0.069	0.005
Initial double limb stance (% stance phase)	22.969	4.616	24.836	5.086	0.003
Final double limb stance (% stance phase)	25.577	5.362	26.667	4.306	0.124

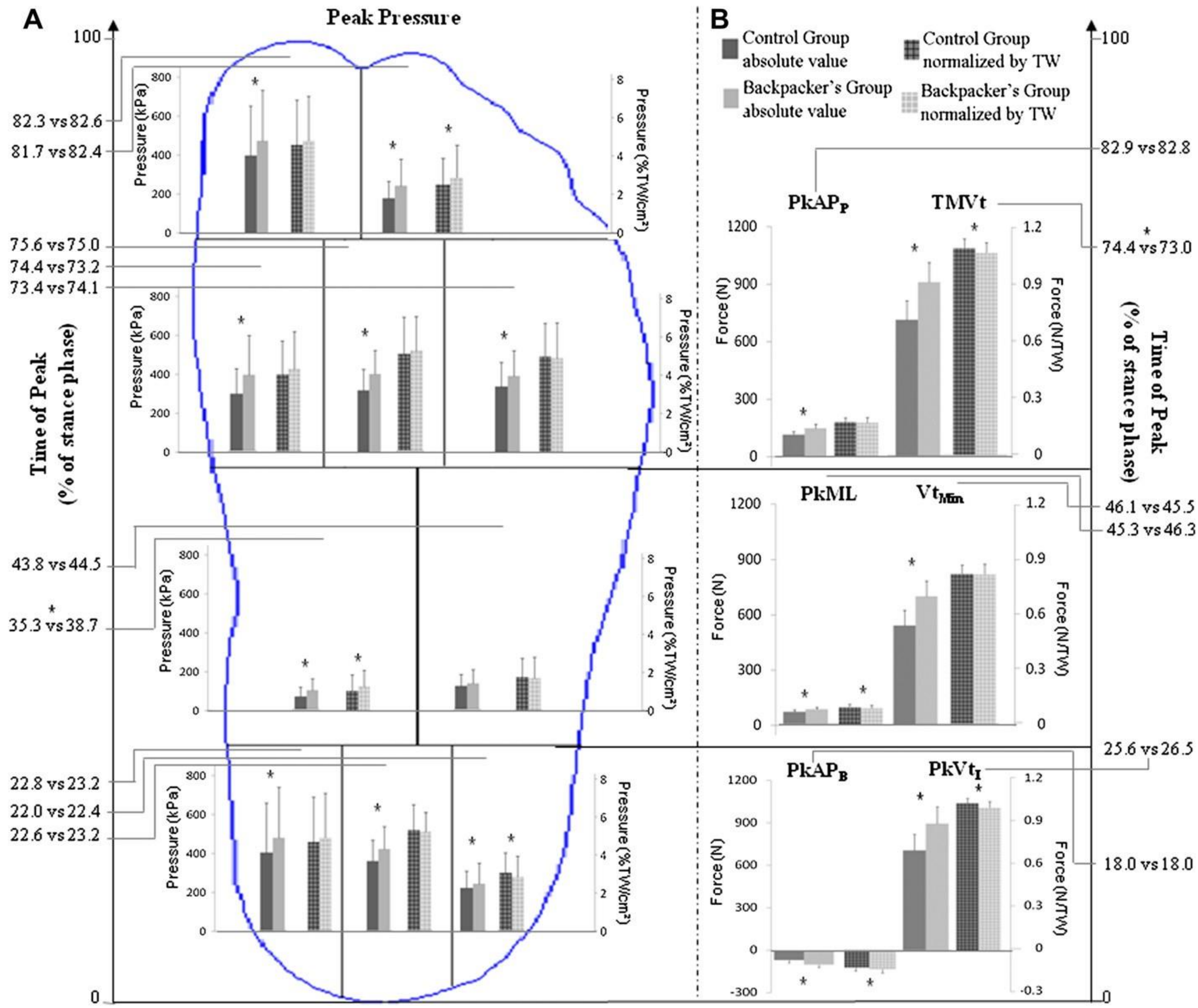

Fig. 1. A. Peak pressure (absolute and normalized values) of each foot's region and respective time. B. Ground reaction forces (GRF) (absolute and normalized values) and respective time of the events. $PkVt_I$ = impact peak of GRF vertical component; Vt_{Min} = minimum between the peaks of GRF vertical component; TMVt = thrust maximum of GRF vertical component; $PkAP_B$ = braking peak GRF anterior-posterior component; $PkAP_P$ = propulsive peak GRF anterior-posterior component; TW = total weight (in control group is equal to body weight and in backpacker group equal body weight plus backpack weight); *Y* axis represents time of the events to control group (first value) and backpacker group (second value). * = statistical difference with $p < 0.05$.

$TMVt_{\_Norm}$ compared to CG (Fig. 1 and Table 2). In BpG $PkMF_{Med\_Time}$ occurred later and $TMVt_{Time}$ earlier compared to BpG. No differences were found for the other time variables (Fig. 1B).

4. Discussion

The present study investigated the influence of occasional load in the GRF and plantar pressure parameters during gait. Other studies have already reported higher GRF during load carriage compared to CG (Birrell et al., 2007; Chow et al., 2005; Harman et al., 2000; Simpson et al., 2012), which corroborates our results. On the other hand, analyses of the GRF normalized by the total weight (body mass plus backpack mass) and the in-shoe plantar pressure while walking occasionally loaded are scarce in literature. The approach employed in this study allowed us to determine the amount of load applied on the foot (absolute values) and changes in the gait pattern (normalized values), as well as the distribution of the forces on the plantar surface of the foot (pressure data) while walking carrying load.

4.1. Rearfoot region

We found an increase in impact forces (absolute values) in BpG. Similar results have already been shown (Birrell and Haslam, 2010; Birrell et al., 2007; Harman et al., 2000; Simpson et al., 2012; Tilbury-Davis and Hooper, 1999). Birrel et al. (2007), analyzing loads of 8, 16, 24, 32 and 42 kg, and Tilbury-Davis and Hooper (1999), analyzing loads of 20 and 40 kg military backpacks, found a proportional increase in vertical and anterior-posterior GRF with the increased load. In contrary, Simpson et al. (2012), analyzing loads of 20, 30 and 40% of body weight, found similar values of GRF parameters between 30 and 40% of the body weight, indicating an

Table 2
. Mean, standard deviation (SD), confidence interval and significant level (*p*) of the differences between CG and BpG for all ground reaction forces and pressure variables.

Variables	Absolute data					Normalized data				
	Mean	Confidence interval			*p*	Mean	Confidence interval			*p*
		SD	Lower	Upper			SD	Lower	Upper	
Force	(*N*)					(N/TW)				
$PkVt_I$	−177.262	74.480	−196.846	−157.679	<0.001	0.032	0.048	0.018	0.045	<0.001
Vt_{Min}	−159.510	56.006	−174.105	−144.915	<0.001	0.003	0.049	−0.009	0.016	0.586
TMVt	−197.264	77.401	−217.259	−177.269	<0.001	0.025	0.051	0.011	0.038	0.001
$PkAP_B$	39.221	20.419	33.946	44.496	<0.001	0.014	0.024	0.007	0.020	<0.001
$PkAP_P$	−32.577	18.204	−37.498	−27.655	<0.001	0.002	0.023	−0.004	0.008	0.549
PkML	−14.182	11.744	−17.327	−11.037	<0.001	0.007	0.014	0.003	0.011	0.001
Pressure	(kPa)					(%TW/cm^2)				
$PkRF_{Med}$	−88.775	78.721	−110.915	−66.634	<0.001	−0.123	0.880	−0.376	0.129	0.331
$PkR\ F_{Ct}$	−62.284	79.487	−84.413	−40.155	<0.001	0.107	0.982	−0.172	0.387	0.443
$PkRF_{Lat}$	−21.046	61.709	−37.889	−4.202	0.015	0.204	0.662	0.018	0.390	0.032
$PkMF_{Med}$	−32.183	35.782	−41.950	−22.417	<0.001	−0.215	0.488	−0.345	−0.086	0.002
$PkMF_{Lat}$	−14.166	52.876	−29.691	1.359	0.073	0.063	0.686	−0.136	0.262	0.529
$PkFF_{Med}$	−97.372	149.339	−138.535	−56.209	<0.001	−0.276	1.721	−0.750	0.198	0.248
$PkFF_{Ct}$	−85.274	76.039	−107.600	−62.948	<0.001	−0.183	1.048	−0.469	0.104	0.206
$PkFF_{Lat}$	−55.269	9.987	−80.843	−29.695	<0.001	0.095	1.468	−0.314	0.504	0.642
PkHlx	−74.604	167.317	−119.411	−29.796	0.002	−0.241	1.616	−0.695	0.214	0.293
PkToes	−62.868	87.000	−87.088	−38.647	<0.001	−0.363	1.164	−0.669	−0.057	0.021

The acronym of the variables can be seen in session *Data Analysis* in Methods. TW = total weight. Negative values indicate that the BpG presented larger magnitudes than CG; only in $PkAP_B$ variable the interpretation is different, where positive values indicate that the BpG presented larger magnitudes than CG.

attenuation of the force progression with female hikers walking with 40% of their body weight. In the present study, the GRF normalized data also indicate alteration in the gait pattern during backpackers' gait. The different populations among the studies may be the reason for the differences (recreational female hikers (Simpson et al., 2012) and untrained young adults (present study) vs. military (Birrell et al., 2007; Tilbury-Davis and Hooper, 1999)) in adaptation on GRF parameters during load carriage.

On the other hand, the $PkAP_B$ was larger (absolute and normalized values). It may indicate that the braking forces are potentiated (increased more than backpack mass) during occasional loaded gait. Birrel and Haslam (2010) also found higher absolute braking forces with load carriage (military). We did not find other studies analyzing braking forces normalized by the total weight to compare to our results. The anterior-posterior force helps slow the body down during the initial part of the gait cycle (Birrell and Haslam, 2010). Its increase seems to be related to blister development (Knapik et al., 1997). Birrel and Haslam (2010) suggested that load carriage increases the pressure on the skin and causes more movement between the foot and the shoe through higher propulsive and braking forces, thus increasing the risk of blister. The absolute pressure increases in all RF regions (medial, central and lateral) in the present study supports this notion. This relation ($PkAP_B$ and RF pressure increase) may be one of the mechanisms that contribute to blister development, which is the most common injury related to load carriage (Cooper, 1981; Knapik et al., 1992).

4.2. *Midfoot region*

The medial MF was specially needed during BpG. Larger absolute and normalized values were found compared to CG. It may be read as an adaptation in the gait pattern as a result of load carriage. For the lateral MF, the opposite behavior was found. Similar absolute and normalized peak pressures were shown between BpG and CG. It may indicate a protective strategy for relieving the pressure on the lateral MF by putting more load on the lower loaded regions (medial MF).

Regarding Vt_{Min}, the BpG presented larger magnitudes of absolute and similar magnitudes of normalized data. It indicates that there was no alteration in gait pattern as a result of carrying a backpack. Birrel et al. (2007), analyzing military hikers, and Simpson et al. (2012) analyzing female hikers, found an increase in medial-lateral impulse as compared to normal gait (no load condition). These results can be related to decrease of stability (Birrell et al., 2007). In the present study, analyzing other variables related to medial-lateral axis (PkML), we also found an increase in medial-lateral forces while loaded walking (absolute values). However, the normalized values indicated that this increase in PkML is not proportional to the weight of the load. Therefore, even when load carriage seems to be a lower stable condition (Birrel et al., 2007; Simpson et al., 2012; absolute data from this study), some gait adaptation may be developed in order to reduce this instability as indicated by the normalized PkML.

4.3. *Forefoot region*

Considering the pressures and GRF acting at the FF, as expected all the variables ($TMVt_{Abs}$, $PkAP_{P\_Abs}$, $PkHlx_{Abs}$, $PkToes_{Abs}$, $PkFF_{Med\_Abs}$, $PkFF_{Ct\_Abs}$ and $PkFF_{Lat\_Abs}$) showed larger magnitudes in BpG compared to CG. The medial FF was the region that presented the highest increase in the pressure when a backpack was used (97.4 kPa, $CI_{95\%}$ 138.5 to 56.2), while the lowest increases occurred in lateral FF (55.3 kPa, $CI_{95\%}$ 80.8 to 29.7). It indicates a higher recruitment of the medial region to support load carriage. By normalizing the data we expected that there were no differences between groups. However, in the PkToes, the values were larger in the BpG. It suggests that during occasional loaded gait the toes region was more needed than in the unloaded gait. BpG also showed lower $TMVt_{Norm}$. Possibly this has occurred because the backpack promotes an increase in forward lean due to the posterior location of the center of mass during gait (Birrell and Haslam, 2010). Thus, the forces required to advance the body from the mid-stance to toe-off were reduced as a consequence of the decrease in the passive movement of the body (Birrell and Haslam, 2010).

4.4. *Time variables*

A longer duration of stance phase and initial double stance was found in BpG as compared to CG. Female hikers wearing a backpack with 30e40% of their body weight and military personnel carrying loads of 8, 16, 24, 32 and 40 kg also showed longer duration of the stance phase compared to the no load condition (Birrell et al., 2007; Simpson et al., 2012). Singh and Koh (2009), Hong and Brueggmann (2000) and Chow et al. (2005) found in primary school students carrying a backpack with between 10 and 20% of their body weight a larger initial double stance compared to no loaded gait. Even with older participants carrying heavier backpacks (32.2% of the body mass, $CI_{95\%}$ 29.5e34.8), our data corroborates with theirs. One possible explanation for this behavior is that walking with a backpack raises the combined center of mass of the backpack and body in posterior and superior fashion. It induces postural imbalance for static and dynamic conditions (Hong and Brueggemann, 2000; Singh and Koh, 2009). The longer double stance may be an attempt to minimize the duration of unsteady single-limb stance (Hong and Brueggemann, 2000). This mechanism brings down the combined center of mass, providing a counter effect to stabilize the gait (Singh and Koh, 2009). The $PkMF_{Med\_Time}$ occurred later and $TMVt_{Time}$ earlier in BpG than CG. The increase of the initial double stance may promote this delay in $PkMF_{Med}$, while the posterior shifting of the center of mass (Birrell and Haslam, 2010) may be responsible for the alterations in $TMVt_{Time}$.

For the adult population, a load limit is not well established. A varying range of heavy loads are carried by different populations. The total load masses carried by soldiers average 40 kg: in some situations they could be required to carry loads of up to 76 kg (Reynolds et al., 1999). Korean beverage workers usually carry approximately 53.4 kg (ranging from 20 to 80 kg) while carrying backpacks (Chung et al., 2005). Tourist trekkers in New Zealand carry backpacks with up to 29% of their body weight for five or more consecutive hours over distances of 11 or more kilometers per day (Lobb, 2004). In all of these populations a high injury incidence was described. Recently, a well-grounded load limit of 30% of body mass was established for female recreational hikers (Simpson et al., 2011a, b). In our study, we adopted a BMI of 30 kg/m^2 as load normalization criterion. The 95% confidence interval of the applied load in our study was 29.5e35.8% of body mass. The load adopted in our study, even while based on other criterion, was just slightly higher than the load limit previously proposed (Simpson et al., 2011a, b). It reinforces that the load selected in our study was successful in putting a potentially harmful load on the musculoskeletal system.

Some possible limitations in this study should be considered. First, the backpack load used was not the same for all participants; we could have normalize the load using either percentage of body mass or a fixed load: however, since the locomotor system of people with BMI � 30 kg/m^2 is considered more susceptible to injuries (Ko et al., 2010; WHO, 2000), we preferred to use the BMI of 30 kg/m^2 as load criterion in order to promote a possible harmful load. We did not intend to reproduce obesity features in our participants, but only the total amount of mechanical load found in obese subjects (which is differently located compared to backpakers). It seems to us that this was an effective way of doing so. Second, the gait speed adopted in the present study was the one with which the subjects felt more comfortable (self-selected), and such behavior can influence the characteristics of the force. We opted for the self-selected speed in order to prevent disturbances in the gait pattern and ensure normal walking (Cavanagh and Ulbrecht, 1994; Hennig and Rosenbaum, 1991). Thus, we analyzed the unloaded and loaded self-selected gait (which we considered a more realistic condition), which does not mean that the participants walked at the same speed using both gaits. Small variations in walking speed are not critical for peak pressure measurements (Taylor et al., 2004). Our subjective analysis during the data collection indicates that the speed of the two conditions was similar. Finally, the pressure analysis considered only the vertical forces: therefore, we do not know about the distribution of the shear forces. As far as we know, there are very restricted devices that are able to perform this kind of analysis.

5. Conclusions

In conclusion, we observed an overall increase in the GRF and plantar pressure parameters, as well as alterations in gait pattern during occasional loaded gait (BpG) as compared to CG. The medial MF and Toes were the most used regions during occasional loaded gait while the lateral RF was used less. Regarding the other regions, the increase seemed to be proportional to the weight of the backpack (higher absolute values in BpG and similar normalized values than CG). A protective behavior in BpG was evidenced by the diminished magnitude of impact and propulsive forces. On the other hand, the shear forces increased more than the proportion of the load, which may mean higher susceptibility to blister development. Further investigation assessing the effects of training or different materials (shoe, insole, socks, etc.) on the GRF and plantar pressures in occasionally loaded people (students, hikers, military personnel, etc.) may be important in improving the capacity of the musculoskeletal system to handle potential harmful conditions.

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