

Gait Characterization of Subjects Under Overload Conditions: Obesity and Backpack Use

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Gait Characterization of Subjects Under Overload Conditions: Obesity and Backpack Use.

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Key – words: gait, obese, backpacker, GRF, plantar pressure

Dedication

To Ana Helena and Jorge

To my parents

To my nephews

To my family

By the Unconditional love and support.

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Abstract

The human gait is a very special movement to the human being. This movement can be affected by various conditions, like the presence of overload. Obesity is considered a health condition, which requires a permanent overload on the loco motor system. The presence of excess weight is not confined exclusively to the obese population. So, in recent times, the use of backpacks for different population groups has been a recurring option for temporarily transporting loads.

The implications of the excess load in the loco motor system are poorly understood. Several recent studies focused on the impact of the excessive body weight on energetic gait in obese adults. Those who addressed the biomechanical component of the gait emphasize the ground reaction forces (GRF), plantar pressures and the range of motion (ROM) separately. Our purpose in this research is to perform a characterization and comparison of the walking gait of obese individuals and backpackers. The different components of gait were studied in an integrated approach.

The GRF were recorded by a Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating at 1000 Hz, a Bertec amplifier system (model AM 6300, Bertec Corporation, Columbus, USA) and a Biopac analog-digital converter (Biopac System, California, USA); the plantar pressure distribution was assessed by a Pedar (Novel, Munich, Germany) insole pressure system. Three, non-coplanar, digital video camera Sony DCR-HC62E (Sony Corporation Japan), operating at 50 Hz, were used to gait characterization together with the Dvideow (Dvideow2004-Digital Video for Windows version 5.0, Laboratory of Instrumentation for Biomechanics & ETF Institute of Computing, Unicamp) software and dedicated MatLab routines.

The sample was selected by convenience. The participants were 20 obese individuals (OG), aged between 45 and 75 years and BMI higher or equal to 30 Kg/m², and 11 healthy adults of normative weight (CG). These 11 individuals were also tested wearing a loaded backpack that allowed reaching an overall “BMI” of 30 Kg/m², constituting the backpackers group (BG).

GRF was calculated during the stance phase, as well as the plantar pressure of 10 distinct regions of the foot plantar surface and the range of motion (ROM), during the stance phase, of the segment of the trunk (for the calculation of the angle of the trunk, we considered a midline between the two acromions and the two iliac crests in order to get the angle of the trunk vertical medium), and the joints of lower limb.

At the end of this work it is to be noted that both groups subjected to load have shown changes in the pattern of gait. The strategies employed in both groups were similar. Most of the differences were found in the temporal parameters of gait: speed, cadence and stride length are lowest in obese individuals and backpackers. These modifications aim to minimize the impact of GRF, to which they are subjected while walking.

Regarding plantar pressure values, we noticed that obese individuals have lower values compared to the other two groups. However, when we compared the control group with the backpackers one, the latter showed higher values of plantar pressure.

The ROM is lower in obese groups and backpackers, except for the knee joint with values similar to the ones of the individuals with normative weight. The segment of trunk adopts a different position depending on whether we consider obese individuals (extension) or backpackers (flexion).

We can say that obese individuals, throughout their lives, will adopt strategies to efficiently execute this activity. We can, somehow, say that these are more prepared for the impact of overload than the backpackers. However, the permanent overload is always present in the loco motor system structures, causing injuries to the musculoskeletal system.

The findings suggest the need to develop strategies that promote the prevention of possible injury at the foot of these individuals. These strategies can pass by the construction of an orthosis (insole) that absorb the GRF to which they are subject the individuals in overload.

Key-words: Obese, Backpackers, Overload, Gait, GRF, Plantar Pressure, Kinematics, Shear Stress, ROM.

Resumo

A marcha é um movimento muito especial do Homem. Este movimento pode ser afetado por várias condições, nomeadamente a presença de sobrecarga. A obesidade é considerada uma condição de saúde que ocasiona uma permanente sobrecarga no sistema locomotor. De facto, a presença de excesso de peso não está somente confinada à população obesa, mas a todos aqueles que carregam cargas no seu dia-a-dia. Recentemente a utilização de mochilas é recorrente em diferentes populações, constituindo uma sobrecarga temporária sobre o sistema locomotor.

Contudo, as implicações da sobrecarga no sistema locomotor ainda não estão totalmente entendidas. As grandes maiorias dos estudos debruçaram-se sobre o consumo energético dos indivíduos obesos, os que abordam os aspetos biomecânicos da marcha enfatizam, de uma forma separada as forças de reação ao solo (FRS), pressão plantar e ROM.

Deste modo, propusemo-nos a realizar uma investigação que nos permitisse a caracterização e comparação da marcha de indivíduos obesos e mochileiros, numa abordagem integrada dos diferentes componentes da marcha.

Os dados de FRS foram recolhidos através de uma plataforma de forças Bertec (model 4060-15, Bertec Corporation, Columbus, USA) operando a 1000 Hz, um amplificador Bertec (model AM 6300, Bertec Corporation, Columbus, USA) e um conversor analógico / digital Biopac (Biopac System, California, USA) as pressões plantares através do sistema Pedar (Novel, Munich, Germany) e os dados cinemáticos através de três câmaras digitais, não complanares Sony DCR-HC62E (Sony Corporation Japan) operando a 50 Hz. Para o processamento de imagens vídeo, usou-se o software Dvideo2004-Digital Video for Windows, version 5.0, Laboratory of Instrumentation for Biomechanics & ETF Institute of Computing, Unicamp.

A amostra foi selecionada por conveniência. Os participantes foram 20 indivíduos obesos (OG), com idades compreendidas entre os 45 e 75 anos e Índice de Massa Corporal (IMC) superior ou igual a 30 Kg/m² e um grupo de 11 indivíduos saudáveis de peso normativo (CG). A estes 11 indivíduos,

posteriormente, foi colocada uma mochila perfazendo um “IMC” de 30 Kg/m², constituindo o grupo de mochileiros (BG).

Avaliaram-se as FRS durante a fase de apoio, assim como as pressões plantares em dez regiões distintas do pé. Foi também calculada a ROM, durante a fase de apoio no tronco (segmento formado por uma linha que une os dois acrômios e as duas espinhas ilíacas ântero-superior, para obtenção do ângulo do tronco vertical) e articulações do membro inferior.

No final deste estudo foi possível constatar que os indivíduos sujeitos a sobrecarga alteram o seu padrão de marcha, sendo as estratégias empregues similares. As maiores diferenças registaram-se nos aspetos temporais da marcha: velocidade, frequência e comprimento do passo são menores nestes grupos. Estas modificações têm como objetivo minimizar o impacto das FRS a que os indivíduos estão sujeitos durante a marcha.

Os valores de pressão plantar são mais baixos no OG enquanto o BG apresenta valores mais elevados do que nos outros dois grupos.

A ROM é menor nos grupos sujeitos a carga, à exceção da articulação do joelho que apresenta valores muito próximos do CG. A posição do tronco foi diferente entre os grupos. O OG e o CG caminham numa posição mais ereta enquanto o BG caminha numa posição mais anterior.

Os resultados sugerem que os indivíduos obesos adotando ao longo das suas vidas, estratégias de forma a se tornarem mais eficientes. Sugerindo que os indivíduos obesos estão mais adaptados ao impacto da carga. A presença permanente da carga predispõe estes indivíduos a lesões no sistema locomotor. Verifica-se a necessidade de se desenvolver estratégias que promovam a prevenção de possíveis lesões no pé, permitindo que a marcha se realize de um modo confortável. Estas estratégias podem passar pela construção de uma ortótese (palmilha) que absorva as FRS a que estão sujeitos os indivíduos em sobrecarga.

Palavras-chave: Obesidade, Mochileiros, Sobrecarga, Marcha, GRF, Pressão Plantar, Cinemática, Lesões Cisalhamento, ROM.

List of Abbreviations and Symbols

10 Logx	Base 10 logarithm of x
BG	Backpackers Group
BMI	Body Index Mass
BW	Body Weight
%F _{_ap_area}	Percentage distribution of anterior-posterior component of GRF for plantar area
F _{apb}	Breaking (negative) peak of the anterior-posterior GRF component
F _{app}	Propulsive (positive) peak of the anterior-posterior GRF component
F _x	Component Anterior-posterior of GRF
F _y	Component Medio-lateral of GRF
F _z	Component Vertical of GRF
F _{z1}	First peak of vertical force
F _{z2}	Second peak of vertical force
F _{zmin}	Peak intermedium of vertical force
GC	Control Group
GRF	Ground Reaction Force

I_{apb}	Impulse Braking Component of GRF
I_{app}	Impulse Propulsion Component of GRF
I_{vt}	Impulse of Vertical Component of GRF
OG	Obese Group
ROM	Range of motion
SP	Stance Phase
SPSS	Statistical Package for the Social Sciences
T_{fz1}	Time of first peak of vertical force
T_{fzmin}	Time of intermedium of vertical force
T_{fz2}	Time of second peak of vertical force
T_s	Angle of trunk in relation to the ground
p	p value
% P	Percentage distribution of plantar pressure for area
P_T	Pressure Total
Δ	Variation

Chapter 1

General Introduction and Thesis Structure

1. Introduction

1.1 Walking

The gait is a simple daily activity and one of the main skills of the human being. This activity is one of the most important skills that enables us, through locomotion, to hold spaces in various contexts (Perry, 2005; Winter, 1991, 2009).

Gait and running are the most natural ways of human locomotion. Amadio (1996) reports that walking allows us of taking part in various forms of daily activities. This involves distinct patterns of complex neurological structures established movements, synchronized with other functions of the human locomotor apparatus. The locomotion pattern is individually defined, and sets itself over time (Hansdorff, 2005; Terrier & Schultz, 2003).

Human locomotion is described as a complex biomechanical process involving an intricate interplay between neuronal functions, muscular and skeletal, and inertial forces that result in the smooth progression of the body moving through space (Duarte & Zatsiorskyb, 2000; Malouin & Richards, 2000; Sacco, 2000; Souza, 2005; Whittle, 2007).

The interplay of these forces can cause constant imbalances during the transfer of weight from one leg to the other, when the individuals are moving forward, trying to recruit the center of gravity, through various mechanisms of a complex system, which involves neuronal functions, muscular and skeletal disorders, acting in constant integration, even when they play different roles (Duarte & Zatsiorskyb, 2000; Souza, 2005).

The gait cycle is composed of several phases. It begins when one foot contacts the ground and ends when that foot contacts the ground again.

During this cycle, each limb passes through two phases: stance phase and swing phase (Enoka, 2000; Winter, 2009). The stance phase accounts for approximately 60 %, and the swing phase for approximately 40 %, of a single gait cycle. The stance phase is considered when the reference foot is in contact

with the ground and is divided into four periods: loading response, mid stance, terminal stance, and pre swing.

The loading response begins with initial contact, the instant the foot contacts the ground (normally, the heel contacts the ground first). Loading response ends with contralateral toe off, when the opposite extremity leaves the ground. Thus, loading response corresponds to the gait cycle's first period of double limb support (Rose & Gamble, 2005).

Midstance begins with contralateral toe off ends, when the center of gravity is directly over the reference foot (that this phase, and early terminal stance, the phase discussed next, are the only times in the gait cycle when the body's center of gravity truly lies over that base of support (Rose & Gamble, 2005; Whitle, 2007).

Terminal stance begins when the center of gravity is over the supporting foot and ends when the contralateral foot contacts the ground. During stance, around 35% of the gait cycle, the heel rises from the ground . Preswing begins at contralateral initial contact and ends at toe off, at around 60 % of the gait cycle. Thus, preswing correspond to the gait cycle'a second period of double limb support (Perry, 2005; Whitle, 2007).

Swing phase is divided into three periods: initial swing, mid swing, and terminal swing. The initial swing begins at toe off and continues until maximum knee flexion (60°) occurs. The mid swing is the period from maximum knee flexion until the tibia is in vertical position, or perpendicular to the ground. Terminal swing begins when the tibia is vertical and ends at initial contact (Perry, 2005; Winter, 2009).

The analysis of the gait normally considers, as a reference, the right foot, in order to make it easier to understand the different phases in analysis.

Figure 1 illustrates schematically the different phases of motion, so that a faster reading of the operating cycle can be done.

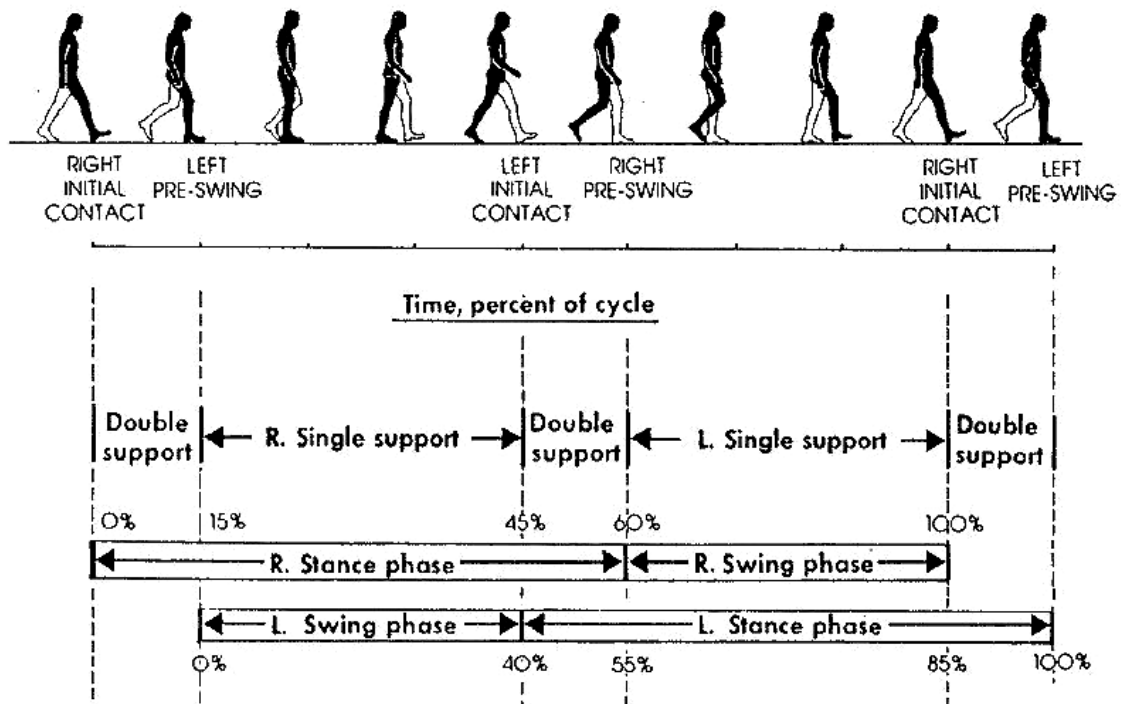


Figure1. Phases of gait (adapted from Plas, 2001).

1.2. Ground Reaction Forces

Knowledge of ground reaction forces (GRF), as well as their distribution on the plantar surface of the foot (plantar pressures) are the most important factors for a good understanding of the foot's kinetic during gait (Gravante et al., 2003; MacPoil, 2000; Orlin & McPoil, 2000; Vazand, 2001).

The GRF components are the most common parameters in the study of motion (Vaughn, 1999a; Winter, 1991, 2009).

In walking, the GRF are the expression of the Newton's 3rd law of motion regarding the force applied by the body to the ground. This force is the result of muscle actions and body weight transmitted through the feet (Barela et al., 2006; Deursen, 2004; Duarte & Zatsiorskyb, 2000).

The largest of the GRF components is the vertical one (F_z), which accounts for the acceleration of the body's centre of mass in the vertical direction during walking. Thus, when the acceleration is positive, which occurs at the stage of double support, GRF is particularly high. Similarly, when the acceleration is

negative, what happens during simple support, the GRF has lower values than the body weight, this is because there is inertial upward a vertical force, that contracts the gravity, associated with the movement of the contralateral limb. So the centre of gravity is at its highest point (Deursen, 2004; Vaughn, 1999b; Winter, 2009).

The horizontal GRF (anterior-posterior) is considerably smaller than the vertical GRF. This force is normally called F_x and it can have a maximum amplitude of 25 % BW (Winter, 2009). In the braking phase it assumes a negative value. The negative value is caused by the braking action of the foot coming down in front of the center of gravity, indicating that it is pushing backward over the person. In the push-off phase F_x is positive when the body moves forward (Richards, 2001; Whittle, 2007).

The medio-lateral GRF (F_y) is related to lateral balance during walking. Its magnitude is less than 10 % of BW in most situations. The F_y acts, firstly, in the medial direction during the loading response and then acts laterally during the rest of the stance period. Lateral shear reaches its peak in the terminal stance (Richards, 2001; Winter, 2009).

1.3. Plantar Pressure

The gait pattern is influenced by plantar pressure distribution which expresses the interaction between the GRF and the foot / ground interface. Some factors that are known to influence the pressure distribution are the structure of the foot, body weight, gait speed, ground structure, alignment of the foot in static position and kinetic momentum (Cavanagh et al., 1991; Dowling et al., 2004; Filippin et al., 2008; Hills et al., 2001a; Wearing et al., 2004).

The knowledge of the distribution of forces by the sole of the foot in stance phase is crucial to realize which of the areas of the foot are more burdened and for how long (Cavanagh & Ulbrecht, 1994; Orlin & McPoil, 2000). Plantar pressure peaks have required greater attention, as both show great potential to cause damage to the plant tissue (Caselli et al., 2002b; Hills et al., 2001b; Mickle et al., 2010; Mueller et al., 2005).

The study of the distribution of plantar pressure has gained increased importance, as it allows a better understanding of postural and biomechanical implications. In the specialized literature, there are many studies on this component of the gait, held in healthy populations, in persons with pathology and in different age groups (Deursen, 2004; Dowling et al., 2001; Fabris et al., 2005; Filippin et al., 2008; Hills et al., 2002a; Mickle et al., 2010; Nyska et al., 1996a; Orlin & McPoil, 2000).

The majority of studies about plantar pressure feature different divisions of the plantar surface of the foot, which makes it difficult to analyze and characterize the functional behavior of the foot. The most frequently used divisions include forefoot, rear foot and mid foot. In some studies these areas are still subdivided (Burnfield et al., 2004; Cavanagh & Ulbrecht, 1994).

Most researchers pointed out that foot zones with higher values of plantar pressure are the rear foot and the forefoot (Azevedo & Nascimento, 2009; Bacarin et al., 2009 ; Birtane & Tuna, 2004; Hills et al., 2001c; Mueller et al., 2008a; Tuna et al., 2004).

1.4. Kinematic aspects of Gait

Gait analysis is increasingly used for a better understanding of the behavior of the various joints involved in this task (Cornwall, 2002; Hansen, 2002). The kinematic description of the gait was done primarily in terms of behavior throughout the cycle of the angles formed by two adjacent segments (Chambers & Sutherland, 2002; Lin et al., 2010) . Analysis of angular measures in sagittal plane is the most widely used because it is the most accurately reproducible. In this plan the movements made are large, with small variability among individuals. The frontal and transverse plans feature a high variability, causing lesser reliability in the results (David, 2000).

Kinematic analysis of the gait has been used as an important research methodology in evaluation of normal human or pathological gait. It has been

applied in the diagnosis of neuromuscular and musculoskeletal changes (Cutlip, 2008; Kirkley, 2006; Perry & Burnfield, 2010).

2. Impact of overload in human gait

Several factors affect the normal patterns of gait. The presence of overload is singled out as one of these conditions (Birrell & Haslam, 2010; Browning & Kram, 2007; Foti et al., 2000; LaFiandra et al., 2002).

The overload during the gait can be divided into two groups: permanent and occasional. As permanent overload are deemed obese individuals. That persistent loading of the musculoskeletal system of the obese has been implicated in predisposition to pathological gait patterns, loss of mobility and subsequent progression of disability (Bouchard et al., 2009; DeVita & Hortobágyi, 2003; Gordon & Friedmann, 2002; Ko et al., 2010).

Regarding the occasional overload, the use of a backpack has also been linked to an increased risk of orthopedic injuries, muscular tension, fatigue and back pain (Birrell & Haslam, 2009; Grimmer et al., 2002; Mackiea, 2008; Negrini, 2007).

2.1. Obesity

Obesity is currently one of the biggest public health problems in the world. In Western countries the prevalence of obesity varies between 20% and 50%, depending on the region, gender, age and race (Ford & Mokdad, 2008 ; Odgen et al., 2007; World. et al., 2000).

In Portugal, the prevalence of obesity was considered within the framework of an epidemiological study nationally driven by the Portuguese Society for the Study of Obesity. The results, published in 2000, showed that approximately 35% of the Portuguese population between 18 and 65 years were overweight, and that 14.4% were obese (Carmo, 2000; Nobre & Jácome, 2004).

Obesity is defined by excess fatty tissue in the body, being considered a chronic disease, interrelated directly or indirectly with certain pathological situations. It is generally accepted that excess weight predisposes the body to a number of

diseases, especially cardiovascular disease, type 2 diabetes mellitus, some cancers and osteoarticular diseases (Ghu, 2009; Harvey, 1999; Haslam, 2005; Kopelman, 2000; Kumanyika, 2002; World et al., 2000).

For Wilding (2001), obesity is probably the result of sedentary lifestyles, in combination with a diet rich in fats; however, not all people who have this type of lifestyle become obese, which may indicate that, in some cases, the origin of obesity is genetic.

According to McInnis (2000), the main factors of obesity are the physical inactivity and the dietary factors. He argues that without a change in dietary habits, combating obesity is ineffective.

In the other hand scientific evidence proves the importance of physical activity for the prevention and maintenance of weight loss (Bouchard et al., 2009; Capodaglio, 2009; Carmo, 2000; Costaza, 2005; Fox & Hillsdon, 2007; Giles-Corti, 2003; Hill & Wyatt, 2005; Ling et al., 2011a; Matsudo & Matsudo, 2004; Wareham, 2007).

Kraemer et al. (1999) conducted a study with thirty-one overweight women (mean age 35.4 ± 8.5 yr) who were randomly placed into either a control group (Con; $n = 5$), a diet-only group (D; $n = 5$), a diet +aerobic endurance exercise training group (DE; $n = 5$), or a diet +aerobic endurance exercise training + strength training group (DES; $n = 5$). After 12 weeks, the three dietary groups demonstrated a significant ($p \leq 0.05$) reduction in body mass, % body fat, and fat mass. No differences were observed in the magnitude of loss among groups, in fat-free mass, or in resting metabolic rate. The DE and DES groups increased maximal oxygen consumption, and the DES group demonstrated increases in maximal strength. Weight loss resulted in a similar reduction in total serum cholesterol, low-density lipoprotein cholesterol, and high-density lipoprotein cholesterol among dietary groups. These data indicate that weight loss during moderate caloric restriction is not altered by inclusion of aerobic or aerobic + resistance exercise, but diet in conjunction with training can induce remarkable adaptations in aerobic capacity and muscular strength despite significant reductions in body mass.

Sharing the same perspective, Rocca (2008) assessed 22 healthy women, aged 25 to 50, with a BMI greater than 30 Kg/m². For three months they were submitted to strength training held three times a week for one hour, with an intensity between 60% to 70%, one maximal repetitions and thirty minutes of aerobic exercise at 70% of peak VO₂, monitored by the heart frequency. The authors concluded that, after 12 weeks of a physical exercise program, there was significant reduction of values related to the visceral fat (waist circumference, hip circumference, waist-hip circumference's ratio).

The presence of load has been linked to the mechanical changes observed in the loco motor system. These changes may cause discomfort during exercise, particularly during the gait. The largest barrier to engaging in physical activity among obese individuals is the difficulty in moving (Hills et al., 2002b; Larrieu et al., 2004).

They also referred painful complaints in the knee joint and lumbar spine (Fabris et al., 2005; Gelber, 2003; Griffin & Guilak, 2008; Grotle et al., 2008; Hills et al., 2002b; Wearing et al., 2006).

The gait is a largely prescribed exercise for weight loss attempts and maintenance, because it is one of the most popular activities and no special requirements are needed for its practice (Browning & Kram, 2007; Reilly et al., 2004).

2.2. Backpackers

The use of backpacks to carry load has been widely adopted by different population groups, including students, postmen, military, hikers and others (Birrell & Haslam, 2010; Fowler et al., 2006; Gillet et al., 2007).

This way of transporting load has been proven to be a good choice, allowing the individual to maintain adequate stability and positioning (Chansirinukor et al., 2001b). The backpack enables the individual to increase its ability to carry load, which may however come to cause damage, particularly in situations where the backpack is used inappropriately (Bryant, 2004; Hong et al., 2007).

As a consequence, some studies have been conducted to identify the biomechanical and physiological impact of this occasional overload on the musculoskeletal system (Birrel et al., 2007; Browning & Kram, 2007; Knapick et al., 1996). In fact, this situation causes additional tension on the musculoskeletal structures (Al-Khabbaz et al., 2010; Knapcik & Harman, 1996; Ko et al., 2010).

Studies conducted with backpack users haven't quite focused on the impact of load in the loco motor apparatus. It is therefore important to assess the answers from the kinematics to provide future guidelines for the gait performance with backpacks.

2.3. Gait characteristics facing overload

2.3.1. Ground Reaction Forces

In this chapter, we shall consider some studies which we believe are relevant for a better understanding of the gait in obese individuals, and backpackers.

Several researchers suggest that obese adults change their gait pattern when compared with their peers from eutrophic weight (Amamdacoomarasamy et al., 2008; Hsiang & Chang, 2002; Nantel et al., 2006; Powell, 2005; Spyropoulos et al., 1991). The same is observed in users of backpacks, for load transportation (Birrel & Haslam, 2010; Birrel et al., 2007; Birrell & Haslam, 2009; Knapick et al., 1996; Knapick et al., 2004).

Among the factors that can change the gait is the cargo weight, because the greater the mass of an object, the greater the force needed to produce its acceleration, which can naturally be applied to the use of backpacks (Flores et al., 2006).

Studies on obese adults reported kinematic changes in spacio-temporal variables. Parameters such as speed, cadence, stride length, posture and balance during the swing phase appear altered with the presence of obesity (DeVita & Hortobágyi, 2003; Holt, 2004; Spyropoulos et al., 1991).

Gait analysis in obese children has revealed differences in spacio-temporal parameters similar to those of obese adults. Some of these studies found that the cycle of gait and the stance phase are longer while observing a reduced cadence (Birrel et al., 2007; Browing & Kram, 2007; Hansdorff, 2005; Lloyd & Cooke, 2000; Perry, 2005; World et al., 2004).

Spyropoulos (1991) compared the length of the step and the differences in variation of angles in the joints of the lower limb, between obese and normal-weight men. He found that obese men walked at a slower freely chosen speed (1.09 m^{-1}) and with smaller steps (reduced step amplitude).

Messier (1996) studied the GRF in obese adults during the gait. His study found that the vertical GRF peak increases in an almost direct proportion with the body weight. The vertical peak was approximately $1.0 \times$ body weight, which is consistent with a slow selected auto speed (1.0 m.s^{-1}). The peak absolute value of the anterior- posterior and mediolateral components of GRF also increased in proportion with body weight.

In a study carried out with 15 male soldiers, carrying backpack loads ranging between 8 and 40 kg, the results have shown changes in the values of the anterior-posterior and vertical GRF. These values were observed even when the load was of only 8 kg (Birrel et al., 2007).

Wang et al. (2001) evaluated the gait of 15 backpackers, their findings were that there was a decrease in single support time and an increase double support time. Similar results were found by Song (2003), in a research made with children who use a backpack to carry a load of 15% to 20% of body weight.

Hsiang & Chang (2002) studied the effect of speed and loading condition on the reliability of the GRF. Fifteen experienced subjects, walked between three to five different speeds with and without load. The load was placed on the back or in front of the trunk. The results of the study indicated that the addition of load and increase of speed had consequently increased the magnitude of the forces at the stance phase correspondent to weight acceptance. The value of the momentum in the push-off phase also increased. These values increased regardless of the load location. The authors concluded that the increase speed

with load mobilizes the centre of gravity of its usual position, having an adverse effect on the gait pattern

2.3.2. Plantar Pressure

As far as plantar pressure is concerned, various research works have been carried out in different groups of population subjected to load. The plantar pressure distribution studies assessed plantar pressure peaks during stance and gait, and found higher values in the entire plantar area for obese children when compared to eutrophic ones; however, the most significant differences are in the mid foot and forefoot areas, probably due to the structural and functional modifications of obese children's feet. This behavior also occurs in obese adults when compared to eutrophic adults, both in static and in dynamic conditions (Birtane & Tuna, 2004; Gravante et al., 2003; Hills et al., 2001c).

When comparing the values of plantar pressure between obese and non-obese adults, the results show that the regions of rear foot, forefoot and halux were measurably high. This is in line with other studies conducted in populations subjected to load (Birtane & Tuna, 2004; Burnfield et al., 2004; Gravante et al., 2003; Knapick et al., 1999b; Pau et al., 2011b; Ribas & Guirro, 2007b; Teh et al., 2006).

The increased forefoot pressure values are of major concern as the forefoot region of the foot is composed of small bones and has a decreased ability to dissipate forces associated with dynamic weight-bearing tasks. Such excessive weight-bearing forces might cause damage to the foot (Caselli et al., 2002b; Dowling et al., 2004; Norkin & Levangie, 1992).

Some studies compared the pressure exerted on the feet when an individual carries a load in a backpack as opposed to unloaded individuals. In walking, the higher peak plantar pressures have been reported at the halux, first, second and third metatarsal heads with no agreement regarding to the location of the highest values in the normal and pathological forefoot (Hsi, 2004; Kellis, 2001; Martínez-Nova, 2011; Nyska et al., 1996a).

Some studies have found that plantar pressure was moderately dependent on body mass index (Burnfield et al., 2004; Gravante et al., 2003; Hills et al., 2001b).

Based on static and dynamic plantar pressure records, results suggested that the increased foot contact area caused by the long-term bearing of additional mass is due to a flattening of the longitudinal arch of the foot (Fabris et al., 2005; Hills et al., 2001c).

In contrast, in the temporary loading condition, despite higher pressures, the foot complex appears to be able to maintain the longitudinal arch (Nyska et al., 1996a) . This effect of the temporary loading condition is opposite to what is observed in the obese population. The higher static forces were distributed over a larger area, thereby having minimal effect on pressures experienced by the obese children under the plantar surface of their feet (Dowling et al., 2004; Mickle et al., 2006).

2.3.3 Kinematics

The kinematic aspects of the gait may also be affected by the presence of a load presence. Indeed studies on the load carriage have suggested that adding a load to the normal gait caused significant kinematic changes (Harman et al., 2000; Lee et al., 2009b; Vismara et al., 2010; World. et al., 2000).

Heavy loads were found to induce physiological strain and the alteration of kinematics movement, observing an increase in the amplitude of the angle of trunk flexion, the knee and hip (Attwells et al., 2007; Liu, 2007; Terrier & Schultz, 2003; Wearing et al., 2004; World et al., 2004).

DeVita & Hortobagyi (2003), refer that obese adults tended to assume a more erect posture while walking at the standard speed, with reduced hip flexion ($\sim 5^\circ$) comparatively to individuals with normal weight. The same results were found by other authors (Browing & Kram, 2007; Rossum et al., 2002; Simpson et al., 2012; Wearing et al., 2006).

Spyropoulos et al (1991) compared stride and joint angle differences between obese and normal-weight men, reporting that the obese males walked slower (1.09 m.s^{-1}) with wider steps and similar knee flexion at mid stance, compared with the faster-walking (1.64 m.s^{-1}) of their normal-weight counterparts. However, according to Lelas et al (2003), peak knee flexion during the loading response phase of stance increases with increased walking speed.

According to Hong et al. (2000), a load of 15% to 20% of the body weight (BW) reflects positively in the trunk inclination of backpackers, but there are no significant changes carrying between 10% to 12% BW. However, in another study conducted by Mota et al. (2002), significant changes were found in the trunk flexion and hip position with the use of a backpack with 12% BW of load.

Knapick et al. (1999a) found that the increased load in a backpack, causes an increase of the double support phase duration and greater flexion of the knee joint for shock absorption at the moment of the calcaneus touch.

In fact, when the line of action of a body's weight moves outside its support area, an imbalance is generated contradicted by the existence of a torque in the opposite direction for balance maintenance. The increased load on a person leads to a hip flexion by adjusting the center of gravity. Another adaptation in gait includes greater flexion of the knee joint, the reduced pelvic rotation and an increase in the forecast of length of the double support (Hall, 2000; Knapick et al., 1999a; Knapick et al., 2004).

2.3.4 Shear Stress in Gait

Shear occurs when two forces are in opposing directions such that there is a deformation of the tissue in parallel planes (parallel shear). It also occurs when two forces are in the same direction but with different intensities (shear force) (Yavuz et al., 2007b).

The foot is the most important structure of weight bearing and shock absorption of the human body (Henning, 2003). The presence of overload affects the gait pattern becoming the foot more susceptible to biomechanical changes

(Deursen, 2004; DeVita & Hortobágyi, 2003; Seung-Uk et al., 2010; Spyropoulos et al., 1991).

Among the mechanical factors that cause foot lesions, shear stresses have been either neglected or underestimated (Yavu et al., 2008).

Abnormal and excessive plantar pressure and shear are potential risk factors for high-heeled related foot problems, such as forefoot pain, halux valgus deformity, calluses and ulcers (Cong et al., 2011).

However, many uncertainties remain about the role and critical levels for shear stress and friction in pressure ulcer development. The magnitude of friction force is dependent on the perpendicular force and a characteristic of the interaction of the two objects known as the coefficient of friction (Gefen et al., 2010).

The key stress variables that contribute to skin injury on the plantar surface of the foot would include the magnitude, time, and direction of stresses (Mueller & Maluf, 2002).

Presumably, the longer time the pressure is applied or the more steps a person takes (e.g. increased repetition) with a given magnitude of pressure experienced on each footstep, the higher the risk for skin breakdown (Mueller, 1999).

The magnitude of stress is characterized as the peak plantar pressure during barefoot and shod walking (Cavanagh et al., 1997). The primary directions of stress application generally are thought of as perpendicular or parallel to the skin.

According to Perry et al. (2002), the greatest pressure occurred in the medial metatarsal heads (189 KPa), and the greatest shear force in the lateral metatarsal heads (33 KPa). The interaction of the shear forces revealed that the plantar tissue was stretched to a greater magnitude than it was bunched (24 KPa vs 12 KPa, averaged over all regions).

In fact, most studies stated that the presence of load increases the plantar pressure values in rear foot, forefoot and halux (Birtane & Tuna, 2004; Burnfield et al., 2004; Dowling et al., 2001; Mueller et al., 2005; Pau et al., 2011b; Rai & Aggarwal, 2006)

Plantar shear distribution depends on local frictional properties of the sole, gait velocity, and, most likely, the internal muscle activity (Bus et al., 2002; Yavuz et al., 2007b)

3. Objectives

After conducting the previous bibliographical research, it was clear that most studies have a larger focus on the physiological aspects of gait, submitted to overload. It was apparent that the limited numbers of studies focusing on obese individuals published to date encompass the locomotor characteristics of obese children or specific groups of population like the military and hikers

On the other hand, we were unable to find any studies that compare the impact of occasional versus permanent overload on human gait. Therefore, it became relevant to characterize and compare these two conditions of overloaded gait, so that the impact of these can be assessed in better conditions can be established the strategies adopted by studied individuals.

The previous studies found analyzed the various components of the gait (GRF, plantar pressure and kinematics) independently. It was our goal to perform the characterization of the gait in an integrated approach of the different components.

Faced with this information, the following targets were established for the current study:

1. To characterize the gait patterns of obese adults from the dynamometric and kinematics' point of view.
2. To characterize walking under specific overload conditions (backpack use), addressing it in an integrated approach that includes GRF, plantar pressure and kinematics of backpackers.

3. To compare the gait of adults submitted to permanent vs occasional overloading and its impact on the locomotion system.
4. Establish whether individuals subjected to load had more predisposition to shear forces than individuals with normative weight.

4. Structure of the Dissertation

This dissertation presents a framework drawn from the “Scandinavian model”, which consists of a collection of already published or submitted studies.

The dissertation consists of 6 chapters (listed in table 1). The first chapter presents the general introduction of the dissertation, the second, third and fourth chapters feature articles developed, while the fifth chapter presents the final synthesis and general conclusions. At the end of each chapter, the bibliographical references are presented.

<i>Chapter 1</i>	General introduction, objectives of the study
<i>Chapter 2</i>	Biomechanical Analysis of Gait: comparison between obese and non-obese adults
<i>Chapter 3</i>	The impact of load in the gait of backpackers
<i>Chapter 4</i>	Does occasional or permanent overload differently influence gait in adults?
<i>Chapter 5</i>	Anterior-posterior regional and global shear stress during loaded gait: backpackers vs. obese people
<i>Chapter 6</i>	Synthesis and Final Conclusions

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Chapter 2

Original Research

Biomechanical Analysis of Gait: comparison between obese and non-obese adults

Abstract

The purpose of this study was to characterize the gait patterns of obese adults from the dynamometric and kinematics' points of view. The vertical and anterior-posterior ground reaction forces (GRF), the plantar pressure, and the spatial-temporal parameters and lower limb joint angles (ankle, knee and hip) were recorded by a force plate, an insole pressure system, and a videogrammetric system, respectively for 20 healthy obese adults (body mass index [BMI] = 37.70 ± 4.70 Kg/m²) and 11 lean people (BMI = 23.4 ± 6.03 Kg/m²) during self-selected gait speed. The GRF (body weight normalized values) were significantly different in the intermediate minimum vertical force, the time of first vertical peak occurrence, vertical GRF impulse, and anterior-posterior GRF breaking and propulsion impulses in obese people. Obese people showed lower plantar pressure values (absolute values) in forefoot and hindfoot, and higher values in the midfoot region than the control group. The range of motion of lower limb did not show significant differences, while the spatial-temporal parameters decreased in obese people. The GRF, plantar pressure distribution and spatial-temporal parameters were different, while the lower limb angles were similar between the groups. This suggests that obese people adopt a different walking pattern than lean people in order to minimize the impact of overweight in the musculoskeletal system.

Key words: Obesity, walking, ground reaction forces (GRF), plantar pressure, joint range of motion (ROM).

1. Introduction

Obesity is considered a serious health problem because it is increased worldwide (Abelson & Kennedy, 2004; Azevedo & Nascimento, 2009; Odgen et al., 2007; Puska et al., 2003; Stein & Colditz, 2004), and has a more pronounced impact on morbidity than on mortality (Arterburn et al., 2005; Caselli et al., 2002b).

The inheritance pattern of obesity is thus complex, and environmental factors play an important role in promoting or delaying its development (Faith et al., 2001; Hannah et al., 2011; Irving et al., 2007; Koplan & Dietz, 1999). Several studies pointed out that physical exercise decrease as a primordial factor to the appearance of obesity epidemics (Amadio & Duarte, 1996; Anderson, 2008; Carmo, 2000; Costaza, 2005; Silva, 2008). Thus, the clinical approach to this health condition passes not only by a diet adaptation, but also by physical exercise increase (Browing & Kram, 2007). The gait is a largely prescribed exercise for weight loss attempts and maintenance, because it is one of the most popular activities and no special requirements are needed for its practice (Browing & Kram, 2007; Reilly et al., 2004).

Different studies indicate that obese people modified their walking pattern comparatively with their peers of normal weight (Amamdacoomarasamy et al., 2008; Birtane & Tuna, 2004; Filippin et al., 2008; Hsiang & Chang, 2002; Ling et al., 2011b; Morag & Cavanagh, 1999; Sacco et al., 2001).

Among the factors that can change the gait is the load weight, because the greater the mass of an object, the greater the force needed to produce its acceleration (Flores et al., 2006)

In recent times, many researches have been carried out for a better understanding of the impact of physical activity on obese individuals. Most of the studies have been developed with obese children, and address preferably the physiological aspects of the gait. This way it's relevant to investigate more about obese adult population. On the other hand we did not find any report in the literature related to GRF, plantar pressure and kinematics in an integrated components of gait analysis, so the aim of this study was to characterize the walking of individual obese adults, addressing, in an integrated approach, variables of GRF, plantar pressure, and kinematics.

2. Materials and Methods

2.1. Participants

This study's sample was selected based on convenience. The participants were aged between 46-70 years and had body mass index (BMI) ≤ 25 (control group - CG) or ≥ 30 Kg/m² (obese group - OG). A total of 31 participants were enrolled in this study, of which 9 women and 11 men were for OG, and 4 women and 7 men were for CG (Table 1). The exclusion criteria were any disturbance of balance, musculoskeletal dysfunction or any difficulties in independent locomotion.

The CG was composed of college officials and the OG was composed of college officials and patients from the sleep apnea service of a local hospital (the patients with sleep apnea were controlled and were in good health, according to medical indication).

Table 1: Sample anthropometric characteristics by BMI group.

Anthropometrics variable	Obese group	Control group
Age (yy)	57.9 $\pm$ 7.9	47.55 $\pm$ 14.60
Height (m)	1.61 $\pm$ 0.08	1.62 $\pm$ 0.08
Weight (N)	945.9 $\pm$ 11.4 *	613.81 $\pm$ 8.49
BMI (Kg/m ²)	37.70 $\pm$ 4.70*	23.4 $\pm$ 6.03

*p $\leq$ 0.05

2.2. Assessment

A Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating at 1000 Hz, a Bertec amplifier signal system (model AM 6300, Bertec Corporation, Columbus, USA), a Biopac analog-digital converter (Biopac System, California, USA), an insole pressure system Pedar (Novel, Munich, Germany) and three, non-coplanar, digital video cameras (Digital Video Camera Recorder Sony DCR-HC62E (Sony Corporation, Japan), operating at 50 Hz, and the

Dvideow (Unicamp, São Paulo, Brazil) software were used for gait characterization (Orlin & McPoil, 2000).

2.3. Procedures

The study was approved by the local ethic commission and all participants freely signed an informed consent term that explained the procedures to be performed and the study proposal. Later, the participants were given fitting black clothes and neutral shoes (similar to ballet shoes) with the pressure insole inside.

Reflective spherical markers were placed on anatomic references of the participants in the greater trochanter, the lateral external surface of the knee, the lateral surface of the ankle, the base of the heel and the 5th metatarsal. After a brief adaptation, all participants were asked to walk over a 6 m walkway with a self-selected speed.

The researcher verified what should be the most adequate position in which the participants should start the gait in order to trample on the force plate, so they could start the gait with their right foot, without changing their gait pattern. As such, the plate was positioned at the middle of the walkway; each participant gave three steps before touching the plate. Three valid tests were recorded.

2.3.1. Data acquisition and processing

For the acquisition of the force plate data, the Acknowledge (BIOPAC System, California, USA) software was used. These data were exported to Matlab 7.0 (MathWorks, Massachusetts, USA), in which a program was developed for the processing and calculation of the following variables: duration of the stance phase (SP), 1st peak of the vertical GRF (F_{z1}), minimum between peaks (F_{zmin}) and 2nd peak or thrust maximum of the vertical GRF (F_{z2}); the respective time of occurrence and the vertical GRF impulse (I_{vt}) during the whole stance phase were also calculated. Considering the anterior-posterior GRF component, the breaking (negative) peak (F_{apb}) and impulse (I_{apb}) and the propulsive (positive)

peak (F_{app}) and impulse (I_{app}) were assessed. The GRF data were normalized to body weight (BW) and the times of their events to the duration of the support phase. To analyze the plantar pressures, the foot was divided into 10 regions, as suggested and adapted from previous studies (Giacomozzi et al., 2012; Gurney et al., 2008b; Redmond et al., 2000). In the region where the boundary between the hindfoot and midfoot was located, 73% of the foot length (from toes to heel direction), being the hindfoot, was divided into three equal parts (33% each). The boundary between the midfoot and forefoot was located 45% along this length which was the midfoot and was divided into equal parts (50% each). The forefoot was divided into three regions, that is, 30% medial (first metatarsal region), 25% central (second metatarsal region) and 45% lateral (lateral metatarsals region), and the other two regions were derived from the halux. The data related to the hindfoot were obtained in F_{z1} , while those of the midfoot were obtained in F_{zmin} , and those of the forefoot and halux were obtained in F_{z2} . For video acquisition, digitization and 3D reconstruction of the Dvideow (Unicamp, São Paulo, Brazil) was used. Matlab 7.0 (MathWorks, Massachusetts, USA) software was used for the development of specific routines for kinematic data processing after three-dimensional reconstruction.

In the kinematic analysis, the change of range of motion (ROM) of different joints between the initial phase (0%) and the final phase (100%) of gait was considered, and then the maximum value between the movement of the flexion and extension of joints of the lower limb was calculated.

A synchronism unit between the force platform and the 3 cameras device was used. The plantar pressure system was synchronized with the platform by identifying the time of first contact between the foot and the platform.

2.4. Statistical analysis

The mean of the three repetitions of each subject was computed and all the statistical procedures were performed with these mean values. The normality of the data was verified using Shapiro-Wilk test and the homogeneity of the variances was verified using Levene's test. For the variables that follow the

normal distribution, the T-test for independent sample was used, while for those which do not follow the normal distribution, the Mann-Whitney test was used instead. The results were presented as mean and standard deviation and the significance level adopted was $\alpha=0.05$. The statistical procedures were conducted using the SPSS software (v.17; SPSS Inc, Chicago, IL, USA).

3. Results

Table 2 shows the values of GRF; the differences were statistically significant ($p=0.001$) and the values were higher in the OG at the time of the first peak ($p=0.05$). The intermediate peak (F_{zmin}) shows significant difference ($p=0.01$), though, the higher values were obtained for the OG. Also, the vertical impulse (I_{vt}), the braking impulse (I_{apb}) and the propulsion impulse (I_{app}) were significantly different ($p=0.03$, $p\leq 0.00$ and $p=0.01$, respectively), between groups

Table 2: Means and standard deviations for GRF values for the obese and control groups.

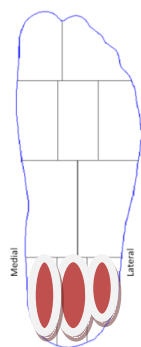
Variable	Obese group	Control group
Stance phase (s)	0.83±0.09*	0.70±0.07
F_{z1} (W)	1.01±0.06	1.02±0.14
T_{Fz1} (%)	28.02±4.22*	24.98±3.87
F_{zmin} (W)	0.86±0.70*	0.76±0.06
T_{Fzmin}	46.92±6.05	44.97±4.97
F_{z2} (W)	1.05±0.10	1.10±0.06
T_{Fz2} (%)	72.74±3.15	73.70±5.53
F_{apb} (W)	-0.13±0.04	-0.14±0.03
$T_{F_{apb}}$ (%)	18.46±3.41	20.21±4.47
F_{app} (W)	0.17±0.05	0.18±0.04
$T_{F_{app}}$ (%)	81.37±4.5	81.60±4.02
I_{vt} (N/s)	47.47±19.37*	34.45±5.56
I_{apb} (N/s)	-2.95±0.67*	-3.80±1.00
I_{app} (N/s)	3.40±0.64*	4.16±1.09
SP(stance phase), F_{z1} (force of peak active), T_{Fz1} (time of F_{z1}), F_{zmin} (force of peak intermediate), T_{Fzmin} (time of F_{zmin}), F_{z2} (force of peak passive), T_{Fz2} (time of F_{z2}), F_{apb} (force of braking), $T_{F_{apb}}$ (time of F_{apb}), F_{app} (force propulsion), $T_{F_{app}}$ (time of F_{app}), I_{vt} (impulse force vertical), I_{apb} (braking impulse), I_{app} (propulsion impulse). * $p\leq 0.05$.		

Table 3 shows statistically significant differences in the cadence ($p \leq 0.001$) and in the step length ($p \leq 0.001$); both were higher for the CG. Despite the fact that the mean speed value was lower in OG, statistical differences were not found.

Table 3: Means and standard deviation for cadence, step length and speed values for obese and control groups. * $p \leq 0.05$

Group	Cadence (step/min)	Step length (m)	Speed (m/s ¹)
OG	73.80±14.42	0.72±11.93*	1.08±0.16
CG	120.18±27.40*	0.97±19.43	1.30±0.17

Figure 1 shows the results of plantar pressure in the rearfoot during the passive peak (F_{z1}). The values observed in the rear foot were significantly higher in the control group. In the central rearfoot, the values were lower in the OG (101.5±34.2 vs. 224.87±38.5 KPa, $p \leq 0.001$). The medial rearfoot value was lower in the OG (112.9±57.4 vs. 174.0±38.5 KPa, $p \leq 0.001$). In the lateral rearfoot, the values were lower in the OG (164.4±53.4 vs. 322.9±98.4, $p \leq 0.001$).



Rearfoot	OG	CG	P
Medial	112.9±57.4	174.0±38.5	0.00*
Central	101.5±34.2	224.87±38.5	0.00*
Lateral	164.4±53.4	322.9±98.4	0.00*

Figure 1: Mean and standard deviation of plantar pressure, in KPa, in the rearfoot. * $p \leq 0.05$.

Figure 2 show that OG had higher values in midfoot. The lateral midfoot region was less required (46.36±37.31 KPa) than the medial midfoot (111.56±37.45 KPa). In CG, these regions were less required (43.75±35.30 KPa for the lateral

and 107.35 ± 40.632 KPa for the medial), though their differences were statistically significant.

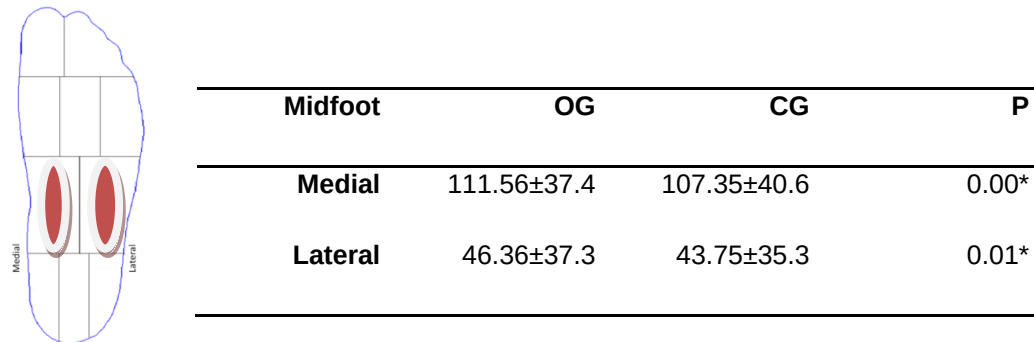


Figure 2: Mean and standard deviation of plantar pressure, in KPa, in the midfoot. * $p \leq 0.05$.

Figure 3 show that the medial and central areas had higher values in the OG. In the lateral forefoot, the values found were 245.71 ± 102.2 vs. 163.17 ± 69.7 KPa, which were not statistically significant ($p = 0.71$). In the forefoot central, the results were higher in OG (228.25 ± 93.1 vs. 115.67 ± 44.0 Kpa, $p=0.07$), and in the forefoot medial, the results were also higher in OG (215.03 ± 112.6 vs. 165.59 ± 110.81 KPa, $p=0.71$). The halux in the obese group was higher than the CG. So the values were 129.31 ± 64.8 vs. 81.82 ± 61.7 ($p=0.001$).

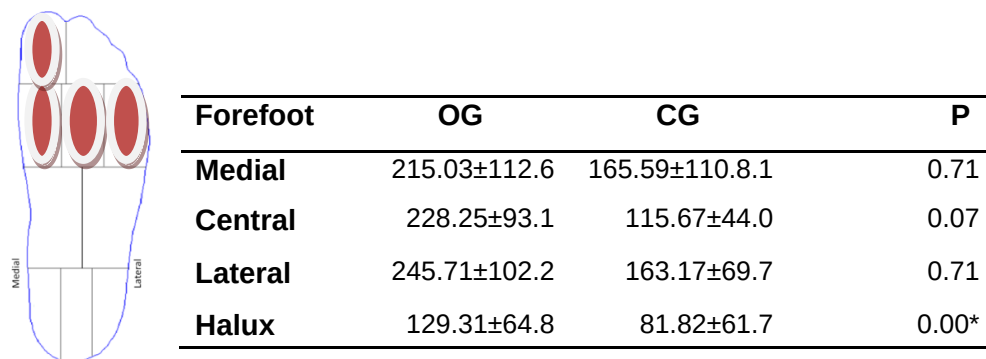


Figure 3: Mean and standard deviation of plantar pressure, in KPa, in the forefoot and halux. * $p \leq 0.05$.

The table 4 shows the variation of the ROM between in the two groups, during the stance phase. We did not found statically significant differences in any ROM.

Table 4: Variation in degrees between the initial (0%) and final (100%) phase of the range of motion (ROM) during the stance phase in the hip, knee and ankle joints, between OG and CG. *p≤ 0.05.

Group	Δ Hip	Δ Knee	Δ Ankle
OG	51.971°±17.722	58.260°±8.724	67.729°±18.931
CG	51.641°±22.036	51.641°±10.095	76.113°±23.895

4. Discussion

The aim of this study was to characterize the walking of obese individuals from the kinetic and kinematical points of view.

The present study found some changes in the GRF, plantar pressure, and lower limb kinematics parameters during obese people's gait, when compared to the control group. In this study, like in other studies involving individuals subject to a higher body burden, there were observed changes in some of the components of gait (Birrell & Haslam, 2009; Filippin et al., 2008; Santos et al., 2005). Some authors suggest that these changes are more evident in individuals with BMI (or its equivalent considering overload) of around 35.5 to 42.3 kg/m² (Browning & Kram, 2007; DeVita & Hortobágyi, 2003). Possibly the results are due to the fact that the average BMI values of the sample were in 37.7 kg/m² ± 4.70, p≤ 0.001, for the OG.

4.1. GRF and temporal variables

From the literature, as it was expected, an increase of load led to a change in the gait pattern. In the OG while walking at a self-selected speed, the GRF absolute values, were generally higher, and had particular implications for the gait pattern of these individuals when compared to their peers with normal weight. Similar results were found on obese samples (Birrell et al., 2007; Chow et al., 2006; Hsiang & Chang, 2002; Sacco et al., 2001; Seung-Uk et al., 2010; World. et al., 2000).

Browning and Kram (2007) studied the effects of obesity on the biomechanics of walking at different speeds. Results showed that absolute GRF were significantly greater for the obese versus normal-weight subjects and decreased significantly at slower walking speeds in both groups.

The GRF values can be explained in part by the values of speed. In our study, the speed values were lower in OG, for the self-selected speed. Non-significant differences of the absolute values of GRF may partly explain these values.

In this study, similar values were found between groups while analyzing the GRF normalized by weight. The lower values of the first peak of the vertical component may be related to a better control of the distribution of the forces during gait, in order to mitigate the impact and protecting passive locomotor structures involved in this mechanism of mechanical shock absorption (Bezerra et al., 1999). The exception was F_{zmin} , that presents significantly higher values (0.86 ± 0.07 vs. 0.76 ± 0.06 , $p=0.01$) in the obese group, possibly due to the lowest freely-chosen speed adopted by this group. In this case, the higher values of F_{zmin} might indicate a lower mechanical efficiency during gait of OG, due to lower energy absorption due to inertial effects of the burden of the contralateral lower limb. This characteristic is typical in the gait of the elderly and pathological conditions (Bennett et al., 2005; Ebersbach et al., 1999; Winter et al., 1990). We can suggest that the maximum lower values of GRF to the relation of body weight may have contribute to the values of peak plantar pressures (Dowling et al., 2001; Gilmour & Burns, 2001; Riddiford-Harland et al., 2000), as it can see below when plantar pressure will be discussed.

In this study the obese group showed an attenuation of the intensity at both points (F_{z1} and F_{z2}) and a notable increase in the vertical impulse (I_{VT}) causing mechanical overload to the level of the musculoskeletal system. Our results are consistent with the results of other studies involving the transport of additional load such as backpacks and pregnancy (Birrel et al., 2007; Hong & Brueggemann, 2000; Oberg et al., 1994; Santos et al., 2005).

According to the literature, values of the braking impulses and propulsion impulses were particularly related to the speed of motion. In accordance, it was found that both impulses were higher in the CG, possibly because this group

walked at a higher self-selected speed. The braking impulse was more dependent on speed, suggesting that individuals model their I_{pb} more than their I_{pp} . On the other hand the propulsive impulse were related to the step length (Peterson et al., 2011) and we observed that the lower value of I_{pp} can be related to the lower value of step length found for the OG.

In the studied sample, it seems possible to recognize a trend for an increase of the stance phase over time (0.83 ± 0.09 vs. 0.070 ± 0.07 , $p < 0.001$), reflected in the higher mean values obtained for the obese subjects. This peculiarity was also found in investigations carried out in adults and obese children in the spatio-temporal aspects of gait which were affected by the presence of excess weight (Birrell & Haslam, 2009; Chow et al., 2006; Grabowski, 2010; Lai et al., 2008b; Martinez-Nova et al., 2008; Sacco et al., 2001). This change was identified as one of the strategies developed in a situation of additional load to maintain balance (Grabowski, 2010; Knapick et al., 1996; Lai et al., 2008b; Nantel et al., 2011).

In this study, the OG presents a longer stance phase which, possibly, was consistent with an increased double support time. This may traduce the adoption of a more efficient behavior to maintain stability during the course of the walking cycle. In addition to these changes, some studies indicate that obese individuals, subject to supplementary load, decreased speed of walking, step length and cadence, concluding that there is a positive relationship between speeds (Derrick et al., 1998; Lelas et al., 2003; Pau et al., 2011b; Peterson et al., 2011). These alterations were observed in this study in which the cadence for the OG lies in the values of 73.80 ± 14.42 steps/min and that for the CG lies in the values of 120.18 ± 27.40 steps/min. However, as already underlined, the values of speed were lower in OG than in CG (1.08 ± 0.16 vs 1.30 ± 0.17 ms^{-1} , respectively). These results are consistent with the results of other studies which show that obese people walk at a slower self-selected speed as compared to individuals with normal weight (DeVita & Hortobágyi, 2003; Grabowski, 2010; MacGraw et al., 1999; Mattson, 1997). The choice to slower the gait speed and reducing stride lengths is directly related to the optimum for energy efficiency (Bertram & Ruina, 2001). Indeed, the mean length

of one step was found to be significantly smaller in the OG when compared to the CG (0.72 ± 11.93 vs. 0.97 ± 11.94 m, respectively). It is assumed that these changes constitute strategies used to reduce the impact of these forces in the musculoskeletal structures (Derrick et al., 1998; Winter, 1991). In fact, the reduction of the relative values for the first and second peaks of vertical GRF component for the obese condition obtained in our study, combined with the increased stance phase seems to be a way to protect the biomechanics system

4.2. Plantar pressure

The values of plantar pressure distribution in the obese population does not meet consensus among researchers. There are authors who reported values of higher plantar pressure in obese individuals when compared with populations having normal weight (Derrick et al., 1998; Dowling et al., 2001), while others report the opposite (Antipatis & Gill, 2011; Birtane & Tuna, 2004; Hills et al., 2001a; Lai et al., 2008a). The most plausible reasons for these conflicting results are the presence, or not, of morphological and functional changes in the structure of the foot, where the plantar arch folding plays an important role (Cavanagh et al., 1991; Fabris et al., 2005; Hills et al., 2001a; Ichiara & Yamada, 2008). Given the mean age of the sample studied (57.9 ± 7.9 years), we can suppose that the presence of load for a long period of time may have caused relevant changes in the anatomy of the foot (particularly at the plantar arch), which could be at least part of a plausible explanation for the observed results relative to the plantar pressure. Other possible explanation should be searched on differences in walking self-selected speed. In general, the overall plantar pressure values obtained in this work were lower in the OG as compared to the group of individuals with standard weight, with the exception of the midfoot region where values were higher (for the OG). The greatest values of plantar pressure in midfoot, during the weight acceptance phase, may result from greater load on the foot, and also from a higher compliance of the plantar arch of the subjects. Similar results were observed in studies of obese children

(Filippin et al., 2008), where the changes of the plantar arch seem to be enough to explain these changes.

In the region of rearfoot, the plantar pressure values registered were lower in the OG. These findings can be explained by the way these individuals touched the ground (a more pronounced mid foot strike), but also by the particular cushioning effect due to the presence of a more or less thick fat pad in the heel and also by the lower values of the GRF in the first peak (Dowling et al., 2001; Gilmour & Burns, 2001; Riddiford-Harland et al., 2000). The plantar pressure values found at the forefoot and halux were higher in the OG, which were consistent with those found in most studies of obese children, pregnant women and individuals carrying loads on backpacks (Filippin et al., 2008; Gaymer et al., 2009; Pau et al., 2004; Rossum et al., 2002), and seem the smaller ROM observed in OG.

4.3. Kinematics

The kinematical results obtained suggest that obese subjects have lower variation in ROM of the joints of the lower limb as compared to the CG. The most significant values of ROM were found on the knee and ankle ($p \leq 0.001$ e $p \leq 0.001$, respectively).

The literature showed that the obesity was associated with attenuated dynamic balance performance (Yadelis et al., 2001). So the ROM of the hip joint in obese individuals expresses a lower oscillation between the beginning and the end of the support phase. This fact probably contributes to the maintenance of stability and balance in walking. DeVita and Hortobagyi (2003) opined that obese adults tend to assume a more erect posture while walking at a standard speed, with reduced hip flexion ($\sim 5^\circ$). It is widely noted that walking in a more erect posture promotes greater stability and lower energy costs (Browning & Kram, 2007; Hakala et al., 1999; Rossum et al., 2002; Wearing et al., 2006).

Always in order to reduce the impact of GRF, there is a greater variation in the knee angle after the heel contact, possibly associated with a decrease in speed (Martinez-Nova et al., 2008). The knee ROM allows the hypothesis that this

combination will function as the attenuation of the GRF during gait in obese people. A similar condition was observed by other investigators such as Spyropoulos et al. (1991), who compared stride and joint angle differences between obese and normal-weight men, and reported that the obese males walked slower (1.09 m.s^{-1}) with wider steps and similar knee flexion at midstance when compared with the faster-walking (1.64 m.s^{-1}) of their normal-weight counterparts, but they could not discern the obesity effects from the speed effects. However, according to Lelas et al. (2003), the peak knee flexion during the loading response phase of stance increased with increased walking speed. Combination of the two studies suggests that, at matched speeds, obese individuals might adopt a more flexed knee during stance than their normal-weight peers. This behavior, although not always observed, was evident in our study, like in others, where increased load discharge also increased support time and amplitude of knee flexion (Birrel & Haslam, 2010; Knapick et al., 1996; Winter, 1991). Indeed, in the study of DeVita & Hortobagyi (2003), there was a decreased knee flexion ($\sim 4^\circ$) during the stance. It is assumed that this result was obtained due to the fact that the BMI was $\geq 40 \text{ kg/m}^2$. Certainly, the greater ROM of the knee flexion seems to improve stability, but leads to an increase in compressive forces which may in turn lead to the emergence of pathology in this joint (Erlichman et al., 2002; Giles-Corti, 2003; Grotle et al., 2008; Lee et al., 2009a).

The decrease of ROM at the ankle, possibly due to the fact that OG have: a gait more slurred, the decrease in muscular strength characteristic in obese individuals and due to lower values of the first peak vertical GRF. Nonetheless, this condition was verified in other researches (Brandt et al., 2000; Nymark et al., 2005; World et al., 2000).

If we relate the results found in the ankle and knee, it is possible to say that this behavior were possibly in order to decrease the impact of GRF and an adaptively way by obese individuals to make this activity more feasible.

4.4. Relationship between the different variables under study

Doing an integrated analysis of the different components of the gait, it can be suggest that obese individuals adopt some strategies, throughout life, to walk more efficiently.

The observed differences in the temporal variables, as increased stance phase decreased the speed, cadence and step length, may have determined the lower values founded for the GRF. This slower rate of the walking cycle has already been shown in other studies of obese children, backpackers and pregnant women (Birrell & Haslam, 2009; Knapick et al., 1996; Lai et al., 2008b; Santos et al., 2005)

Implementing this strategy makes the walking cycle to take longer time (more “drag”), a value which was consistent with the increased time spent in the stance phase. This delay may be an apparent defense of the locomotor system. The same was observed in the study by Charteris et al (1998) with subjects carrying backpacks, which conclude that the increased load causes an earlier contact of the foot with the ground. It also refers that it is a better way to absorb the GRF.

It is well known that the plantar pressure values depend on the structural aspects of the foot and the vertical component of the GRF, so in this study the maximum values of GRF expressed relatively to body weight were lower in CG which may have contribute to the lower values of peak plantar pressures (Dowling et al., 2001; Gilmour & Burns, 2001; Riddiford-Harland et al., 2000). We found that the OG contacted the ground with smaller amplitude of dorsal flexion, aspect that might be associated with the values of GRF, particularly F_{z1} , and a longer support phase. The fact that these areas are supported for longer, together with the anatomical changes occurring in the foot, may explain the difference of values of plantar pressure found between the two studied groups. These results were consistent with those of studies involving individuals under different overload conditions (Dowling et al., 2001; Gilmour & Burns, 2001; Hills et al., 2002a).

The fact that the foot spend longer time in the stance phase made it more exposed to the forces, which creates discomfort (Wearing et al., 2006), the probable explanation for the adoption of more sedentary behaviors. These results were consistent with those of studies involving individuals under overload conditions (Dowling et al., 2001; Gilmour & Burns, 2001; Hills et al., 2002a). The speed and load in the presence of motion affects the moments of flexion /extension of the different joints of the lower limb in healthy subjects (Lelas et al., 2003), which may be one of the justifications for the ROM values found in this study, since the obese group walked at a slower speed (Gehm et al., 2003; Gillet et al., 2007; Lelas et al., 2003; Matsudo & Matsudo, 2004; Winter, 1991).

5. Conclusion

The presence of obesity alters the normal pattern of gait. The modifications become possibly due to the fact that obese individuals, throughout their life, adopted strategies that make them more efficient in gait. This claim stems from the fact that these subjects will acquire certain strategies throughout their life in order to reduce the impact of GRF in this activity. These solutions include a slower self-selected speed and a greater support phase duration. These conditions possibly were on the basis of the lower relative values of GRF obtained for obese individuals. The values of plantar pressure were in general lower in obese due to the possible alterations in the anatomy of the foot, the lower values of speed, GRF and ROM in the ankle.

The lower values of ROM of the joints of the lower limb can be a strategy to maintain balance during the walking cycle.

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Chapter 3

Original Research

The impact of load in the gait of backpackers

Abstract

Backpack has been widely used by students, hikers, and military personnel as a suitable way of transporting load. So, the aim of this study is to characterize walking under specific overload conditions (backpack use), addressing, in an integrated approach, ground reaction forces (GRF), plantar pressure and kinematics of backpackers. A convenience sample composed of 11 participants (4 women and 7 men), with mean body mass index (BMI) of $23.4 \pm 6.03 \text{ kg/m}^2$ was studied. The sample was evaluated on two conditions: (i) walking without backpack, and (ii) walking with backpack. The weight placed on the backpack caused the subjects to have a “total BMI” of 30 kg/m^2 . The mass placed inside the backpack ranged from 11.2 to 20.7 kg (mean = $17.7 \pm 3.4 \text{ kg}$). The participants walked over a 6 m walkway, at a self-selected speed. The ground reaction forces (GFR) were recorded through a Bertec 4060-15 force plate. The plantar pressure were assessed through the PEDAR (Novel) system, and for the trunk, the ankle, the knee and hip joints kinematics, three Sony (50 Hz) digital cameras and the Dvideow software were used. The values of GRF (normalized to “total body weight”) were not significantly different between the two situations. The spatial-temporal parameters decreased during the backpack situation. The plantar pressure’s values were, in general, higher in the loaded condition. The values of plantar pressure were statistically different in the forefoot central ($p=0.001$) and lateral ($p=0.002$), in the midfoot ($p \leq 0.001$ for medial, $p=0.01$ for the lateral), in the halux ($p=0.002$) and in the other toes ($p=0.051$). The joints range of motion (ROM) was not significantly different during the stance phase of both studied conditions. The backpack situation imposed a walking pattern with the trunk in forward flexion position. The backpackers can generally adapt their gait pattern to the presence of load. The values of plantar pressure were, in general, higher when the backpack was used, possibly generating some discomfort. Considering the type of gait adaptations perceived, it is hypothesized that the persistent use of backpacks may potentiate injuries of the locomotion system.

Key words: Backpackers, ground reaction force (GRF), plantar pressure, range of motion (ROM).

1. Introduction

Backpack has been widely used by students, hikers and military personnel to transport loads (Birrel & Haslam, 2010; Birrel et al., 2007; Knapick et al., 1996; Liu, 2007). This way of carrying a load has been shown to be a good option, allowing the individual to maintain posture and gait stability (Wearing et al., 2004). However, studies indicate that load transport through backpack provides an increased stress in different human biomechanical systems, in particular, the locomotor (Attwells et al., 2007; Birrel et al., 2007; Lloyd & Cooke, 2000; Terrier & Schultz, 2003; Vaughn, 1999a; Wearing et al., 2004). Indeed, previous studies indicate that both the peak vertical and anterior-posterior GRF increases proportionally to the load applied (Birrel et al., 2007; Hansdorff, 2005; Lloyd & Cooke, 2000; Perry, 2005; World et al., 2004; World. et al., 2000). Accordingly, the temporal aspects of gait are also significantly altered with load, resulting in significant decrease in step length, cadence, walking speed and the single support time (Chow et al., 2006; Deursen, 2004; Souza, 2005).

Some studies compared the pressure exerted on the feet when an individual walks carrying a load in a backpack. However, in walking, the higher peak plantar pressures have been reported at the halux, first, second, and third, metatarsal heads, but with no agreement regarding the location of the highest values in the normal forefoot (Martínez-Nova, 2011). Whether the load was on the back or held in front, the added load was carried more on the forefoot than on the heel (Hsi, 2004; Lloyd & Cooke, 2000; Morag & Cavanagh, 1999). Previous studies on the load carriage have suggested that adding a load to the normal gait caused significant kinematic changes (World. et al., 2000). Heavy loads were found to induce physiological strain and the alteration of movement kinematics, with an observed increase in the amplitude of the angle of trunk flexion, the knee and hip (Attwells et al., 2007; Liu, 2007; Terrier & Schultz, 2003; Wearing et al., 2004; World et al., 2004).

Load carriage for a prolonged period of time can be detrimental to the musculoskeletal system (Al-Khabbaz et al., 2010). Harman et al (2000) inferred that increasing either load or speed, results in increased stress to the musculoskeletal system, as evidenced by bone-to-bone forces, ground reaction forces and impulses, and muscle electrical activity, which most probably increases the rate of fatigue and risk of injury.

Most studies were conducted in children or in transporting military loads in backpacks (Chow et al., 2006; Jacobson et al., 2003; Knapick et al., 1996; Souza, 2005; World et al., 2004). These populations have specific characteristics that may lead to different results when studying about healthy adults carrying loads using a backpack.

Majority of studies refer to the direct and indirect implications of load transport using backpack, but stressed mostly on the physiological aspects of walking. In fact, most of the previously published studies that addressed the direct or indirect implications resulting from the transport of backpacks with different load levels have received greater emphasis on physiological variables, including oxygen consumption. The bibliography consulted did not find studies that covered the different variables of the gait in an integrated way.

So, the aim of this study is to characterize walking under specific overload conditions (backpack use), addressing, in an integrated approach, GRF, plantar pressure and kinematics of backpackers.

2. Methodology

2.1. Sample

This study was of laboratorial nature and exploring character. The sample was selected by convenience from college officials. It was composed of 11 subjects (4 women and 7 men). The mean age of 50.05 ± 2.16 years for women and mean height of 1.57 ± 0.02 m, the mean body weight of (580 ± 0.73) and mean body mass index (BMI) of 23.59 ± 1.19 kg/m². The mean age of 49.66 ± 4.49 years for men and, mean height of 1.74 ± 0.08 m, the mean body weight of (726.66 ± 3.39) and mean body mass index (BMI) of 24.00 ± 1.08 kg/m².

2.2. Instruments and materials

To collect GRF data, a Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating at 1000 Hz, a Bertec amplifier signals system (model AM 6300, Bertec Corporation, Columbus, USA) and a Biopac analog-digital converter (Biopac System, California, USA) were used.

Data on plantar pressure were obtained through a Pedar system (Novel, Munich, Germany). To kinematically obtain and process video images, the software Dvideo2004 (Digital Video for Windows, version 5.0, Laboratory of Instrumentation for Biomechanics and ETF Institute of Computing, Unicamp), was used over images captured from three cameras Digital Video Camera Recorder Sony DCR-HC62E (Sony Corporation, Japan) operating a 50 Hz.

2.3. Procedures

This study was approved by the local Ethical Commission, and all participants freely signed an informed consent term based on Helsinki's Declaration, which explained the purpose and the procedures of the study.

The authors explained to all subjects, the procedures and the method of collecting information, as well as the confidentiality warranties. Later, the participants were given fitted black clothes and neutral shoes (ballet shoe) with pressure insole inside. Reflective spherical markers were placed on anatomic references of the participants in the right and left side: the acromion, the greater trochanter, the lateral face of the knee and ankle, heel and the base of 5th metacarpal. For each participant, the weight to raise their "total BMI" to 30 with backpack was calculated, and then a backpack was filled with sand and fixed in the central area of each subject's back trunk. The mass placed inside the backpack ranged from 11.2 to 20.7 kg (mean mass = 17.7 ± 2.9 kg). This overload was chosen because it is considered to leave the muscle-skeletal system more susceptible to injuries (Ko et al., 2010).

After a brief adaptation, all participants were asked to walk as normally as possible over a 6 m walkway which had the force plate embedded in the middle. Information related to three valid tests, starting with the right leg was collected.

Later, the participants placed the backpack and walked the same way as previously mentioned.

For the acquisition of the force plate data, the Acknowledge software (Biopac System, California USA) was used at a frequency of 1000 Hz. These data were exported to the Matlab 7.0 (Mathworks, Massachuets, USA) software in which a routine was developed to calculate the different relevant variables (Table 1).

Table 1. List of variables and respective symbols.

Variables	Symbol
Stance Phase	SP
First maximum of the vertical force (1 st peak)	F_{z1}
Period of time for the occurrence of 1 st F_z peak	T_{fz1}
Intermediate minimum of the vertical force	F_{zmin}
Period of time for the occurrence of F_{zmin}	T_{fmin}
Second maximum of the vertical force (2 nd peak)	F_{z2}
Period of time for the occurrence of the 2 nd peak	T_{fz2}
Impulse of the force vertical	I_{vt}
Braking (negative) peak of the anterior-posterior force	F_{apb}
Period of time for the occurrence of the braking peak of the anterior-posterior force	$T_{f_{apb}}$
Propulsive(positive) peak of the anterior-posterior force	F_{app}
Period of time for the occurrence of the propulsive peak of the anterior-posterior	$T_{f_{app}}$
Impulse of the braking force	I_{apb}
Impulse of the propulsive anterior-posterior force	I_{app}

The force data were normalized to body weight (F/ BW); the data concerning the temporal variables were normalized by the duration of the stance phase (% stance phase).

To analyze the plantar pressure's distribution, the foot was divided into 10 regions, as adapted from others studies (Cavanagh & Ulbrecht, 1994; Gurney et al., 2008a). The rearfoot and the forefoot were divided in medial, central and lateral, and the midfoot into medial and lateral. The fingers were divided into halux and others fingers.

The videos were processed by the Dvideow software (Unicamp, São Paulo, Brazil). Matlab 7.0 (MathWorks, Massachuets, USA) software was used for the development of specific routines for kinematics data processing after three-dimensional reconstruction.

For the calculation of the angle of the trunk, we considered a midline between the two acromions and the two iliac crests in order to get the angle of the trunk vertical medium (Ts). The next joints were considered for the range of motion (ROM) study: hip, knee and ankle. To calculate the hip angle, we considered the acromion, the greater trochanter and the upper tibial tuberosity.

For the knee angle, we considered the greater trochanter and the upper tibial tuberosity and the lateral malleolus. For the ankle angle, we considered the upper tibial tuberosity, the lateral malleolus and the base of the 5th metacarpal.

The ROM of the different joints was measured as the total amplitude variation during the stance phase. In the values of the trunk, the negative signal refers to the extension of the segment. A synchronism unit was used between the force platform and the 3 video cameras, using a LED and a trigger.

The plantar pressure system was synchronized with the force platform's by identifying the time of the first contact between the foot and the platform.

2.4. Statistical analysis

The normality of the data was verified using Shapiro-Wilk test, and the homogeneity of the variances was verified using Levene's test. For the variables that followed normality, the T-test for independent samples was used. For those that did not follow normality, the Mann-Whitney test was used. The results were presented as mean and standard deviation, and the significance level adopted was $\alpha=0.05$. The statistical procedures were conducted using the software SPSS (v.17; SPSS Inc, Chicago, IL, USA).

3. Results

Table 2 presents the results obtained for the GRF between the two conditions studied. It was found that, the weight (total weight) presented statistically significant difference ($p=0.01$). However, the outcome of other variables studied showed no statistical significant differences, despite a tendency was perceived to higher values of force in the loaded condition.

Table 2. Means and standard deviations for GRF values for the two conditions normal and loaded.

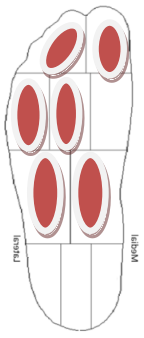
Variable	Conditions		P
	Normal	Loaded	
Weight (N)	613.811±8.490	753.031±139.820	0.009*
F _{z1} (W)	1.020±0.150	1.030±0.158	0.622
T _{fz1} (%)	22.778±8.436	25,290±4,590	0.577
F _{zmin} (W)	0.811±0.129	0.771±0.120	0.792
T _{fmin} (%)	44.976±4.973	42.651±6.890	0.718
F _{z2} (W)	1.013±0.175	1.052±0.141	0.599
T _{fz2} (%)	73.785±5.537	69.542±7.452	0.224
F _{apb} (W)	-0.145±0.038	-0.185±0.043	0.275
T _{fapb} (%)	20.214±4.719	17.522±2.324	0.101
F _{app} (W)	0.184±0.049	0.185±0.054	0.352
T _{fap} (%)	81.601±4.020	79.870±8.286	0.818
I _{vt} (N/s)	34.450±5.562	33.937±0.998	0.922
I _{apb} (N/s)	-3.804±1.009	-3.857±0.969	0.670
I _{app} (N/s)	4.160±1.091	3.935 ±0.990	0.743

F_{z1} (force at the first peak), T_{fz1} (time of Fz1), F_{zmin} (intermedium minimum force), T_{fzmin} (time of Fzmin), F_{z2} (force at the second peak), T_{fz2} (time of Fz2), F_{apt} (peak value of the horizontal anterior-posterior GRF at the braking phase), T_{fapt} (time of Fapt), F_{app} (peak value of the horizontal anterior-posterior GRF at the propulsion phase), T_{fap} (time of Fapp), I_{vt} (impulse of the vertical force), I_{apb} (braking impulse), I_{app} (propulsion impulse). *p≤0.05.

In Table 3, the values obtained for plantar pressure were statistically different between the two studied conditions in the halux (p=0.002), in the other fingers (p=0.05), and in the forefoot central and lateral (p=0.001 and p=0.02, respectively). However, statistically significant differences were also observed in the midfoot central (p=0.001) and lateral (p=0.01).

Table 3. Means and standard deviations for values of plantar pressure, in KPa, in the hindfoot, midfoot, forefoot, halux and other fingers in the normal and loaded conditions.

* p≤0.05.

Variable		Conditions		P
		Normal	Loaded	
Halux		81.82±61.7	227.24±101.06	0.002*
Other toes		89.86±64.67	65.4±38.9	0.051*
Forefoot_medial		165.59±110.8	213.6±96.1	0.158
Forefoot_central		115.67±43.0	279.4±127.1	0.001*
Forefoot_lateral		163.17±69.1	177.7±79.0	0.002*
Midfoot_medial		107.35±40.6	21.27±23.3	0.001*
Midfoot_lateral		43.75±35.3	82.71±44.0	0.011*
Hindfoot_medial		174.0±38.5	184.70±92.6	0.221
Hindfoot_central		224.87±38.5	232.6±112.0	0.210
Hindfoot_lateral		322.9±98.41	204.62±124.9	0.252

The results of ROM are presented in Table 4 showing that the loaded conditions had a higher stance phase. As such, the cadence ($p=0.02$) and the step length ($p=0.00$) had statistically significant differences, being lower in the loaded condition.

The trunk was in flexion (positive values) in the loaded condition and in extension (negative values) in the unloaded condition. The results showed statistically significant changes in the knee ($p = 0.05$) and in the trunk ($p = 0.01$) ROM, during the stance phase.

Table 4. Means and standard values of stance phase, cadence, step length, speed and variation in ROM between 0 and 100% during the stance phase for the trunk, hip, knee and ankle between the normal and loaded conditions. * $p \leq 0.005$.

Variable	Conditions		
	Normal	Loaded	p
Stance phase (s)	0.701±0.07	0.751±0.13	0.250
Cadence (step/min)	120.181±27,40	105.120±37.82	0.021*
Lenght step (m)	0.974±19,40	0.500±5.490	0.001*
Speed (m/s ⁻¹)	1.30± 0,17	1.23±0.17	0.225
Ts (% SP)	-12.679±5.48°	9.207±8.209°	0.171
Hip (% SP)	51.052±22.036°	50.497±17.493°	0.566
Knee (% SP °)	59.641±10.095°	56.854±13.556°	0.757
Ankle (% SP °)	76.113±23.895°	75.410±21.985	0.810

Figure 1 shows the values of ROM in the control group (no loaded conditions) and backpackers group (loaded conditions) in degree during the stance phase (the stance phase was normalized to the stance time in seconds).

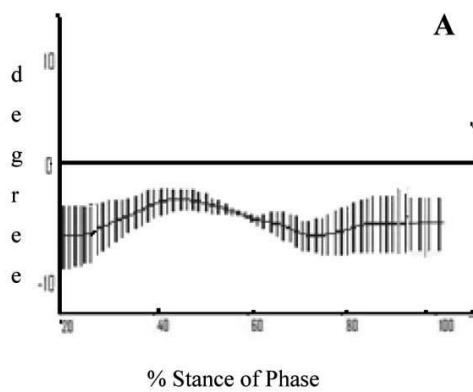


Figure 1. Means and standard deviation in trunk ROM in degree during the stance phase in CG.

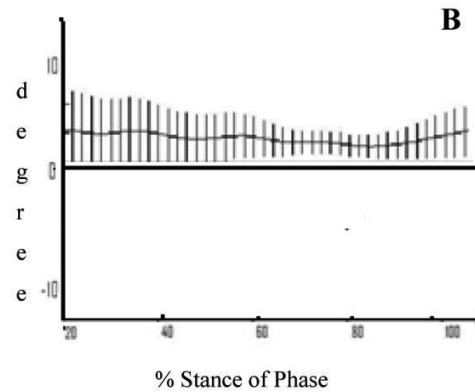


Figure 2. Means and standard deviation in trunk ROM in degree during the stance phase in BG.

The results show that the position of the trunk is distinct among the study groups.

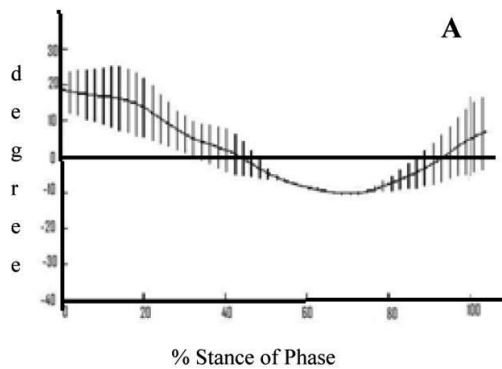


Figure 3. Means and standard deviations of hip ROM in degree during the stance phase, in CG.

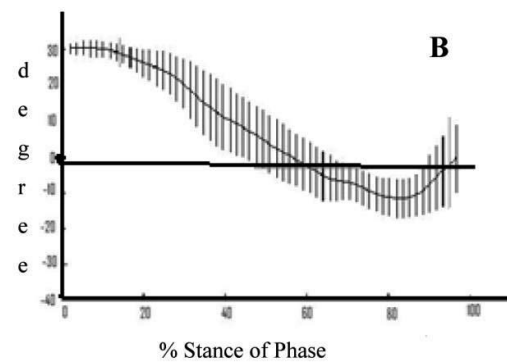


Figure 4. Means and standard deviations of hip ROM in degree during the stance phase, in BG.

The values of hip ROM are similar in the two studied conditions.

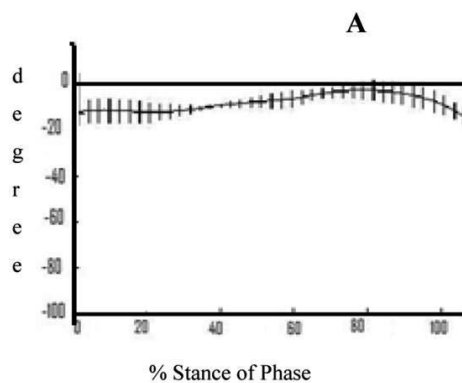


Figure 5. Means and deviation of knee ROM in degree, during the stance phase in CG.

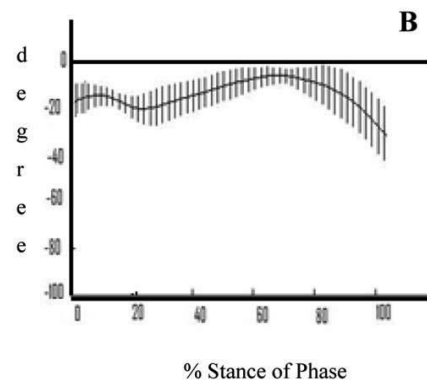


Figure 6. Means and deviation of knee ROM in degree, during the stance phase in BG.

The values of knee ROM are similar in the two conditions studied.

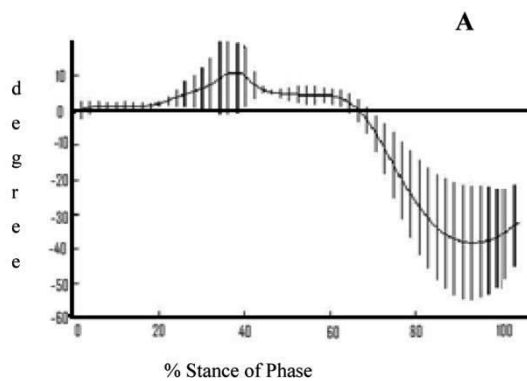


Figure 7. Means and standard deviations of ankle ROM in degree during the stance phase in CG.

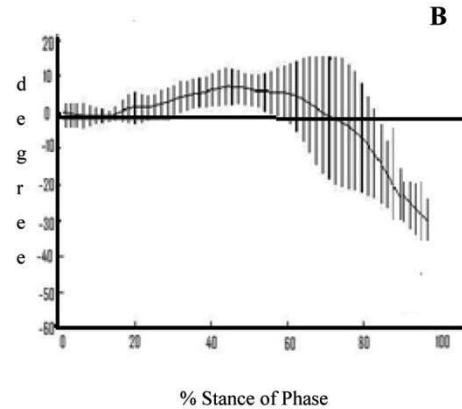


Figure 8. Means and standard deviations of ankle ROM in degree during the stance phase in BG.

The ankle ROM are in means lower in the loaded condition.

4. Discussion

The aim of this study was to characterize walking under specific overload conditions (backpack use), addressing, in an integrated approach, GRF, plantar pressure and kinematics of backpackers.

Non significant differences were found in the parameters extracted from the relative GRF to time functions, between the normal and the overloaded situations, despite the higher absolute average values obtained in the backpack situation. The values of plantar pressure and lower limb kinematics parameters during backpack use were similar to the results observed in other studies of individuals subjected to a high inertial load (Hsiang & Chang, 2002; Terrier & Schultz, 2003; World et al., 2004).

4.1. GRF and temporal variables

According to the literature, the increases of load change some aspects of the gait pattern (DeVita & Hortobágyi, 2003; Perry, 1992; Spyropoulos et al., 1991). In increasing load (adding a backpack with 20% of body weight), it has been shown to increase the magnitude of GRF (Hsiang & Chang, 2002; Lloyd & Cooke, 2000; World. et al., 2000).

The values extracted from this study did not show significant statistical differences between the loaded and unloaded conditions in relative values.

When we consider absolute values there are significant differences on GRF. These results are consistent with the results of other studies conducted in healthy adult subjects and children transporting a backpack load of about 20% body weight, in which it was found that it is still possible to maintain the stability of the temporal variables in those conditions (Bezerra, 1999; Perry, 1992; Safikhani et al., 2011; Vaughn, 1999a).

The adopted gait speed in the present study was one in which the subject felt more comfortable (self-selected) and such behaviour can influence the intensity of the GRF (Pieter et al., 2009).

Most studies referred to individuals submitted to extra-load during walking at a slower speed compared to individuals not subjected to this condition (DeVita & Hortobágyi, 2003; Grabowski, 2010; MacGraw et al., 1999), whereas, in our study, the subjects with backpack walked at a slow speed as compared to the alternative condition.

The spatial-temporal parameters of gait are sensitive to load. These changes, associated with biomechanical changes are produced to maintain the balance during locomotion (Hong & Brueggemann, 2000; Shing & Kohm, 2009; Vismara et al., 2007; World. et al., 2000).

In our research, the means values of walking speed, step length and cadence were lower in the loaded condition. These characteristics were observed in other studies which had reported positive correlations between velocity, duration of stance phase, cadence and step length (Ahomen et al., 2000; Holt, 2004; Lelas et al., 2003; Martinez-Nova et al., 2008; Safikhani et al., 2011). Most authors suggest that these strategies were used to minimize the impact of load (Birrell & Haslam, 2009; Filippin et al., 2008; Malouin & Richards, 2000; Sacco et al., 2001).

Load impact can be assessed through the study of GRF. Accordingly, previous studies on unloaded subjects indicated that when walking speed increases, the peak values of the vertical and anterior-posterior components of the GRF increases (Browning, 2007; Caravaggi, 2010; Grabowski, 2010; Santos et al., 2008); in fact, in our study, the normal condition presented higher relative values in these variables compared to the loaded condition. Regarding speed,

both groups walked without significant differences, which meant that in the backpack situations, they were submitted to an increased joint stress because the reduction in speed led to decrease in acceleration of movement and consequently the moment of force and possibly reduction of stress (Harnold, 2010; Pauk et al., 2010; Vazand, 2001).

Considering the relative values of the propulsion force (F_{app}), it was possible to observe that this variable presented higher mean values in the backpack situation. This was consistent with the reports of other authors (Browing, 2007; Terrier & Schultz, 2003). These results may be, in part, due to the fact that these individuals have walked at a slower speed and associated with a higher unbalance due to the additional load.

According to Kinoshita and Bates (1985b), the presence of load increases the value of the braking impulse. The same was found in our study for the backpack situation, possibly indicate a greater difficulty in this phase of gait.

4.2. Plantar pressure

The knowledge of the plantar pressure distribution is essential to detect in what areas of the foot the overload is more expressive. Several factors have been shown to affect foot pressures including age, walking speed, weight and footwear (Barela et al., 2006; Cavanagh et al., 1991; Fabris et al., 2005; Magee, 2003; Menz & Morris, 2006).

In our study, the values of plantar pressure were higher in the backpack condition, possibly due to the fact that these individuals were occasional users of backpack and were not submitted to changes in the anatomical structure of the feet as a consequence of chronic submission to load. These aspects are explained according to some authors who states that the plantar pressure distribution is not directly related with load (body weight), but to the skeletal structure, the variation of the bone anatomy and the composition and location at the foot plantar surface of the adipose tissue that tends to distribute the pressure, as well as to the biomechanical pattern of load support (Cavanagh et al., 1991; Wearing et al., 2004). This was already established in other investigations (Hong & Brueggemann, 2000; Menz & Morris, 2006; Nyska et al.,

1996a; Pau et al., 2011b). However, higher forces and pressures associated with external loading have also been reported by Nyska et al.(1996a).

The effect of the temporary loading condition was presented by several authors in contrast to the effect of permanent loading (traduced by obesity), where, due to morphological adaptations of the foot, the higher static forces are distributed over a larger area of contact with the ground. (Azevedo, 2009; Barela & Duarte, 2008; Filippin et al., 2008; Morag & Cavanagh, 1999; Nobre et al., 2009). Underlining that this effect may be centred over changes on the plantar arch anatomy, Birtane and Tuna (2004) reported that out of six plantar regions, only the midfoot area recorded a statistically significant increase in peak plantar pressure when obese subjects ($BMI = 30.0$ to 34.99 kg/m^2) were compared to controls. On the contrary, Nyska et al. (1996b) found that walking subjects transporting a backpack loaded with 20 kg do not show any increase of the pressure in the midfoot plantar region. These results are in line with those of the study carried out by Pau et al. (2011b) where the backpack introduces significant increases in the overall contact area (up to 10%) and in the plantar pressure peaks observed in the midfoot and forefoot regions (20 to 30%). We found that the forefoot, halux and other fingers are submitted to a significantly higher plantar pressure in the backpack condition, suggesting that the acute effect of transporting a backpack with a mean added mass of $17.70 \pm 3.0 \text{ kg}$ may not be sufficient to impose anatomical adaptations to load that increase the contacting surface with the ground. Parallel, results can also be explained by the fact that the foot regions affected by high pressure values had little cushion and, therefore, present higher difficulties to adapt to the extra weight and to the associated movement and inertia. These results were consistent with those found in most studies of obese children, pregnant women and individuals carrying loads in backpacks (Crenshaw, 2004; Gaymer et al., 2009; Hoboni et al., 2002; Karadag-Saygi et al., 2010a; MacGraw et al., 1999; Ribeiro et al., 2011).

The fact that plantar pressures present higher values in backpack condition can increase the risk of foot discomfort in these subjects and the appearance of blisters (Dowling et al., 2001; Knapick et al., 1999a; Rossum et al., 2002).

The highest values of plantar pressure in loading conditions may be affected by the values of GRF and ROM. In fact the decline of ROM have been linked with higher values of plantar pressure (Ho et al., 2010). The higher values found in the hindfoot on the load condition were possibly due to the values of F_{z1} and the lowest ROM in the ankle.

4.3. Kinematics

Load is among the factors that can change the gait pattern (Flores et al., 2006). In our study, the users of a backpack had a longer stance phase (0.75 ± 0.13 vs. 0.70 ± 0.07 s, $p= 0.25$); it seem likely that the increase in support time was a strategy used by subjects carrying loads to decrease the impact of peak forces in the muscle-skeletal system (Browing, 2007; Kinoshita, 1985a; Malouin & Richards, 2000; Mann, 2008; Sacco, 2000).

Other preceding researches indicate that backpack loads caused biomechanical kinematic changes including forward inclination of the trunk (Hong & Brueggemann, 2000; Li, 2001; Shasmin, 2007; Souza, 2005). Grimmer (2000) studied the change of posture in young students with a 15% load in the backpack, showing an anterior tilt of the trunk. With a 20% body weight load, Knapick et al. (1996) found that walking with a backpack also projects the trunk forward significantly. In this study, we also observed differences in the trunk posture, corresponding more flexed positions of the trunk to the loaded condition. This posture was imposed for the load applied in the back of the trunk (dorsal area) as similar results were already reported in other studies (Al-Khabbaz et al., 2010; Deursen, 2004; MacPoil, 2000; Singh & Koh, 2009).

Once different investigations have concluded that walking in an erect posture produces greater stability (Hakala et al., 1999; Rossum et al., 2002; Wearing et al., 2006) we can speculate that the backpackers walk with lower stability, or that the trunk tilt is exactly a strategy to guarantee the most proficient relationship between the centre of mass and the centre of pressure to ensure high values of walking stability in the loaded condition. Studying balance with adolescent backpackers, Chow et al. (2006) observed significant perturbations

of balance in both anterior-posterior and medial-lateral directions, concluding that transporting a backpack with a given load may alter the falling risk.

We thought that the more anterior positions of the trunk may have also contributed to the lower values of the ROM in hip in the participants using a backpack. However, our results were not in agreement with other studies who found that hip ROM increases with the presence of extra weight during walking (Attwells et al., 2007; Chow et al., 2006), treated possibly one strategy used by this sample towards maintaining balance during walking.

In the present study, we observed that wearing a backpack implies a similar ROM at the knee joint when compared with the unloaded condition, despite the knee ROM (flexion) is considered as a attenuation strategy for the effect of GRF in loading condition (Cornwall, 2002; Safikhani et al., 2011). Nevertheless, it should be noted that GRF relative values were, likewise the knee ROM, not significantly different between the two conditions. However, the absolute values were in fact different suggesting the need for further knee flexion during load acceptance. The acute characteristic of this loading condition and the possible inexistence of sufficient time to allow walking pattern adaptations may account for this effect.

The ankle ROM, in the backpack condition, was lower than in unloaded walking. In this research was found a lower ROM of the ankle reflects a lower step length and a lower ROM at the hip joint. This result is in accordance with those of other studies in children subjected to loads and obese adults, while walking at a freely-chosen speed (Birrell & Haslam, 2009; Hansen, 2002; Lelas et al., 2003; Malouin & Richards, 2000; Nymark et al., 2005; Stansfield et al., 2006a).

5. Conclusion

The backpackers can generally adapt their walking pattern in the presence of load. The temporal aspects of gait are significantly altered, resulting in a significant decrease in step length, cadence and walking freely-chosen speed. Moreover, differences were found with respect to the values of plantar pressure: the backpack use implies higher values in almost all the foot regions. In the long

term, the higher values of plantar pressure observed as a result of backpack use may cause discomfort and injury to the tissues.

The posture modifications result a better comfort explained by less force to the knee and ankle to compensate the load located in the back.

It is worth noting that the trunk takes a more forward inclined position, which allows speculations to be made about subjects walking with higher instability when carrying a backpack.

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Chapter 4

Original Research

**Does occasional or permanent overload influence
gait in adults differently?**

Abstract

The aim of this study is to compare the gait cycle of adults submitted to permanent and occasional overloading and its impact on the locomotion system. The sample included obese subjects with body mass index (BMI) of $\geq 30 \text{ kg/m}^2$ and subjects with BMI of $\leq 25 \text{ kg/m}^2$ (backpackers' group-BG), walking at a self-selected speed. The ground reaction forces (GRF) were recorded by a Bertec 4060-15 force plate, the plantar pressure distribution by PEDAR (Novel) system, and the range motion (ROM) of joints by 3D kinematics based on Sony (50 Hz) digital video cameras and the Dvideow software. Significant differences between groups were found in the vertical and anterior-posterior GRF, and the values of plantar pressure in midfoot, halux, and other fingers. The values of ROM did not differ significantly between groups, but the trunk in BG was in a slightly more forward tilted position. The strategies to cope with load go through changes in spacio-temporal components of the walking cycle, and the backpackers walked with the trunk in more anterior position.

Key words: Overload, walking, dynamometry, podobarometry, ROM.

1. Introduction

Using a backpack is one of the most common ways to carry loads (Al-Khabbaz et al., 2010). Some population like students and hikers uses them to carry items from place to place (Birrel & Haslam, 2010; Fowler et al., 2006; Gillet et al., 2007). This solution for carrying load has been shown to be a good choice, allowing the individual to maintain the proper positioning and stability (Attwells et al., 2007; Birrel et al., 2007; Chansirinukor et al., 2001a; Rossum et al., 2002). However, studies indicate that the transport of load in a backpack provides an increase in stress in the different human biomechanical systems, in particular, those involved in locomotion. The variables of the gait more sensitive to load seem to be the ground reaction forces (GFR), the values of plantar pressure, and the joints range of motion (ROM) in the lower limb and trunk (Lloyd and

Cooke, 2000; Wilson et al., 2001; Hong and Cheung, 2003; Birrel et al., 2007; Hooper et al., 2007).

Similarly to the transportation of load through the occasional use of a backpack, obesity can also be perceived as a "load", but one that permanently affects the subject (Hills et al., 2001a; World. et al., 2000). Indeed, adult obesity has been associated with a prevalence of musculoskeletal disorders (Gong et al., 2010; Wearing et al., 2006). Considering the increasing number of obese people, several researches focused on this serious public health problem, linking it to a mechanical overload imposed to the locomotion system, causing functional changes of the foot and often pain in the hip, knee and lumbar spine (Wearing et al., 2006).

The literature suggests that the presence of overweight either permanently or occasionally affects the human gait pattern (DeVita & Hortobágyi, 2003; Harman et al., 2000; Ren et al., 2005; Safikhani et al., 2011; Spyropoulos et al., 1991).

Although several studies analyzed the behavior at gait of obese subjects or backpackers, to the best of our knowledge, we did not find any research that compared these two populations. So, the aim of this study was to characterize the gait of adults permanently or casually submitted to overloading, and to analyze the impact on the locomotion system of a similar global load in both groups. This will be tried through the combination of the study of GRF, plantar pressure distribution, and gait kinematics of relevant aspects, to allow more detailed information on how they interact in the human body to reduce the impact of load over the locomotion system (Orlin & McPoil, 2000; Shultz et al., 2009; Wearing et al., 2006). We hypothesized that the different distribution of load and the permanent vs. occasional nature will determine different gait adaptations.

2. Methodology

2.1. Sample

The sample was selected by convenience; the subjects were aged between 46 and 70 years old, with a body mass index (BMI) of $\geq 30 \text{ kg/m}^2$ for the obese group (OG) and BMI of $\leq 25 \text{ kg/m}^2$ for the backpackers group (BG).

The sample included 31 individuals of both sexes. Eleven were part of the BG (7 women and 4 men) and 20 (9 women and 11 men) of the OG. The BG was composed of college officials while the OG was composed of college officials and patients from the sleep apnea service of a local hospital; the patients with sleep apnea were controlled and in good health condition.

The exclusion criteria included any disturbance of balance, musculoskeletal dysfunction or any difficulties in independent locomotion. The BG had a mean age of 47.55 ± 14.60 years; $613.81 \pm 8.49 \text{ N}$ of body weight; $1.62 \pm 0.08 \text{ m}$ of height, and BMI of $23.4 \pm 6.03 \text{ kg/m}^2$. For the OG, the mean age was 57.9 ± 7.9 years, body weight was $980.9 \pm 7.9 \text{ N}$, height was $1.61 \pm 0.08 \text{ m}$ and BMI was $37.70 \pm 4.70 \text{ kg/m}^2$.

2.2. Instruments and materials

To collect GRF data, a Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating at 1000 Hz, a Bertec amplifier signals system (model AM 6300, Bertec Corporation, Columbus, USA) and a Biopac analog/digital converter (Biopac System, California, USA) were used.

Data on plantar pressure were obtained through a Pedar system (Novel, Munich, Germany), and three, non-coplanar, digital video cameras Digital Video Camera Recorder Sony DCR-HC62E (Sony Corporation, Japan) operating at 50 Hz were used for gait kinematics characterization. To kinematically process the video images, the software Dvideow2004 - Digital Video for Windows, version 5.0 (Laboratory of Instrumentation for Biomechanics and ETF Institute of Computing, Unicamp) was used.

2.3. Procedures

This study was approved by the local Ethic Commission, and all participants freely signed an informed consent term that explained the procedures to be performed and the study proposal. This term was based on the Helsinki declaration.

Later, the participants were given fitting and black clothes, and neutral shoes (without sole and insole), instrumented with pressure insoles. Participants were asked to walk freely over a 6 m walkway which had the force plate embedded in the middle. Each person made three valid tests and was asked to start with the right leg and walk at a comfortable speed. For each participant in the BG, the mass necessary to raise their “total (body + backpack load) BMI” up to 30 kg/m^2 was calculated. The extra mass inside the backpack ranged from 11.2 to 20.7 kg (mean value = $17.7 \pm 3.4 \text{ Kg}$). The choice of this value for the “total BMI” was to allow comparison with obese subjects (or the limits assumed for the obesity condition), assuming the fact that this is considered a mechanical load capable of causing damage to the musculoskeletal system in both the short and long term (Ko et al., 2010). The backpack was supported on both shoulders, on the back of the trunk, and secured in this position by the belt of the bag itself, so as to be comfortable and stable to the subject.

For data treatment of GRF, a routine was developed in Matlab, version 7 (Mathworks, Massachusetts, USA), to calculate the following variables: (i) first peak (F_{z1}); (ii) intermediate minimum (F_{zmin}), (iii) second peak (F_{z2}) of the vertical component of the GRF; (iv) the breaking (negative) peak (F_{apb}); (v) the negative the impulse (I_{apb}); (vi) the propulsive (positive) peak (F_{app}), and (vii) the propulsive impulse (I_{app}) of the anterior-posterior GRF component. The stance phase (SP) duration was also calculated.

The force data were normalized to body weight (F/ BW); the data concerning the temporal variables were normalized to the duration of the stance phase (% stance phase). For the analysis of the plantar foot pressures, a Matlab, version 7 (Mathworks, Massachusetts, USA), routine was also developed. An adaptation to the model of the foot division into relevant areas, as recommended by

Cavanagh and Ulbrecht (1994) and Kersting et al. (2008) was done. The foot was divided into 10 regions: the hindfoot and forefoot were divided into medial, central and lateral; the midfoot into central and lateral, and the fingers were divided into halux and other toes.

In each test, the stance time interval, considered between the initial and final contact instances of the foot with the force plate was considered for analysis and consequently digitized from video footage. To calculate the joint angles of the trunk and lower limb, reflective markers were placed in the right and left side of participants in the acromion, trochanter, upper tibial tuberosity, lateral malleolus, calcaneus and the base of 5th metacarpal. The next joints were considered for the range of motion (ROM) study: hip, knee and ankle. For the calculation of the angle of the trunk, we considered a midline between the two acromions and the two iliac crests in order to get the angle of the trunk to the vertical medium (Ts). For the knee angle, the greater trochanter, the upper tibial tuberosity, and the lateral malleolus were considered. For the ankle angle, the upper tibial tuberosity, the lateral malleolus and the base of the 5th metacarpal were considered. The ROM of the different joints was measured by the total amplitude variation during the stance phase.

Synchronization between the force platform data and video cameras was obtained through a trigger, activating concomitantly a LED visible from the 3 video cameras simultaneously. The plantar pressure system was synchronized with the force platform by identifying the time of the first contact between the foot and the platform.

2.4. Statistical analysis

The normality of the data was verified using Shapiro-Wilk test and the homogeneity of the variances using Levene's test. For the variables whose distribution followed normality, the T-test for independent samples was used to compare mean values. For those that did not follow a normal distribution, the Mann-Whitney test was used. The results were presented as mean and standard deviation and the significance level adopted was $\alpha=0.05$. The

statistical procedures were conducted using the software SPSS (v.17; SPSS Inc, Chicago, IL, USA).

3. Results

Table 1 shows the comparative results of the GRF vertical component between the OG and the BG.

The results show that the time to the first peak of the vertical force was significantly higher in the BG ($p = 0.05$). The values of F_{zmin} and the respective time of occurrence was significantly higher in the OG ($p \leq 0.01$ and ≤ 0.05 , respectively). However, the total vertical impulse was not different between the tested groups (51.11 ± 20.90 vs. 33.46 ± 5.17 Ns, $p = 0.11$). The values of F_{apb} ($p=0.01$) and F_{app} ($p=0.01$) were significantly different between groups. Both the propulsion impulse (3.40 ± 3.099 vs. 93 ± 0.99 Ns, $p = 0.02$) and the braking impulse (-3.85 ± 0.96 vs. -2.95 ± 0.67 Ns, $p \leq 0.001$) were statistically different, with higher mean values observed for the BG.

Table 1. Mean and standard deviation for GRF values for obese and backpacker groups.

Variable	Group		P
	Obese	Backpackers	
Weight (N)	945.919 $\pm$ 114.601	753.031 $\pm$ 139.820	0.001*
F_{z1} (%BW)	1.011 $\pm$ 0.063	1.030 $\pm$ 0.158	0.071
T_{fz1} (%)	28.027 $\pm$ 4.221	25,290 $\pm$ 4,590	0.058
F_{zmin} (%BW)	0,862 $\pm$ 0,071	0.771 $\pm$ 0.120	0.013*
T_{fzmin} (%)	46.920 $\pm$ 3.671	42.651 $\pm$ 6.890	0.051
F_{z2} (%BW)	1.056 $\pm$ 0.101	1.052 $\pm$ 0.141	0.136
T_{fz2} (%)	72.748 $\pm$ 3.145	69.542 $\pm$ 7.452	0.212
F_{apb} (%BW)	-0.134 $\pm$ 0.043	-0.185 $\pm$ 0.043	0.104
T_{fapb} (%)	18.465 $\pm$ 3.301	17.522 $\pm$ 2.324	0.796
F_{app} (%BW)	0.175 $\pm$ 0.063	0.185 $\pm$ 0.054	0.011*
T_{fapp} (%)	81.355 $\pm$ 4.530	79.870 $\pm$ 8.286	0.858
I_{app} (N/s)	3.408 $\pm$ 0.995	3.937 $\pm$ 0.998	0.020*
I_{apb} (N/s)	-2.958 $\pm$ 0.679	-3.857 $\pm$ 0.969	0.001*
I_{vt} (N/s)	51.110 $\pm$ 20.902	33.46 $\pm$ 5.17	0.117

F_{z1} (force at the first vertical peak), T_{fz1} (time of F_{z1}), F_{zmin} (force at vertical intermediate minimum), T_{fzmin} (time of F_{zmin}), F_{z2} (force at the second vertical peak), T_{fz2} (time of F_{z2}), F_{apb} (horizontal peak force of braking), T_{fapb} (time of F_{apb}), F_{app} (horizontal peak force of propulsion), T_{fapp} (time of F_{app}), I_{vt} (impulse of vertical force), I_{apb} (impulse of braking force), I_{app} (impulse of propulsion force). * $p \leq 0.05$.

Figure 1 shows the mean values of GRF in the two groups studied. It was noted that there are significant changes in values of F_{zmin} values of GRF and in the F_{apb} and F_{app} .

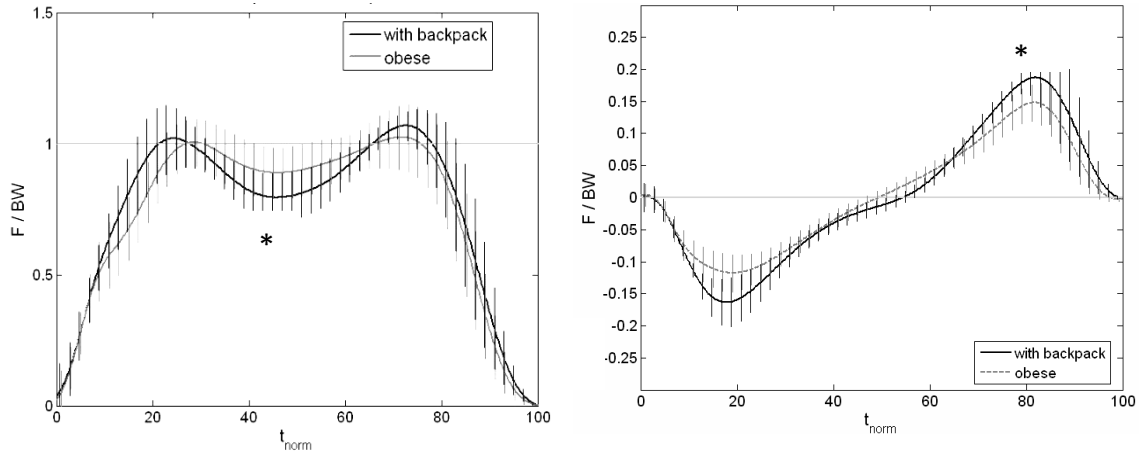


Figure 1. Mean and SD bars of force to time curves of the vertical (left) and anterior-posterior (right) components of the GRF, comparing the obese and backpackers groups. The force values were normalized to body weight (F/BW), and time (t_{norm}) was expressed as a % of the total duration of the stance phase. * $p \leq 0.05$

From Table 2, it can be seen that the values of plantar pressure were significantly different at the halux ($p=0.005$), the other fingers ($p=0.002$), the midfoot medial ($p=0.005$), and the midfoot lateral ($p=0.05$).

Table 2. Mean and standard values of plantar pressure, in KPa, in the hindfoot, midfoot, forefoot, halux and other fingers, comparing the obese and backpackers groups. * $p \leq 0.05$.

Foot area		Group		
		Obese	Backpackers	P
Halux		129.31±64.80	227.24±101.01	0.005*
Other fingers		81.82±61.72	195.2±112.90	0.002*
Forefoot_lateral		173.66±110.81	209.6±94.82	0.341
Forefoot_medial		208.39±104.92	279.46±127.19	0.242
Forefoot_central		245.71±102.20	170.5±83.43	0.383
Midfoot_central		43.75±35.33	21.27±23.32	0.005*
Midfoot_lateral		107.35±40.63	82.71±44.04	0.051*
Hindfoot_lat		156.52±68.35	184.70±96.70	0.365
Hindfoot_cent		196.22±67.41	232.81±117.61	0.172
Hindfoot_med		172.29± 63.01	204.62±132.40	0.433

The results in Table 3 shows that the time of stance phase was significantly different ($p=0.013$). The values of cadence ($p=0.022$) and step length ($p=0.00$) were significantly different between groups, and presented mean lowest values for the OG.

Joints ROM results showed that the trunk in the OG was kept in extension (negative values), while BG was in flexion.

Table 3. Mean and standard values for stance phase, cadence, step length, speed and ROM during the stance phase for the trunk, hip, knee and ankle joints between the obese and backpackers groups.

Variable	Group		<i>P</i>
	Obese	Backpackers	
Stance phase (%)	0.83±0.09	0.74±0.13	0.013*
Cadence (step/min)	73.80 ± 14.42	105.12±37.82	0.022*
Step length (cm)	72.73±11.93	96.9±15.81	0.001*
Speed (m/s)	1.08±0.16	1.30±0.17	0.003*
Ts (0-100% SP)	-7.697±3.492°	9.207±8.209°	0.001*
Hip (0-100% SP)	51.971±17.722°	50.497±22.036°	0.226
Knee (0-100% SP)	58.260 ±8.724°	56.854±13.556°	0.374
Ankle (0-100% SP)	67.729±18.931	75.410±21.985	0.612

* $p \leq 0.005$

We found statistically significant differences in trunk joint's ROM between the two groups. Figure 2 shows the values of ROM in the obese group and backpackers group in degree during the stance phase (the stance phase was normalized to the stance time in seconds).

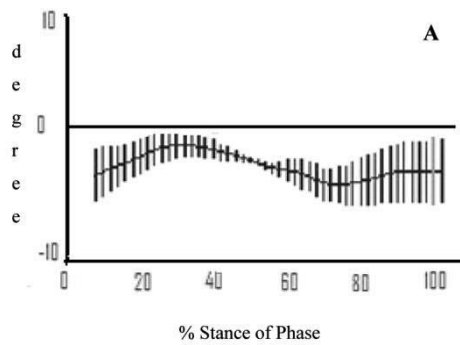


Figure 2. Means and standard deviation of trunk ROM in degree during the stance phase, in OG.

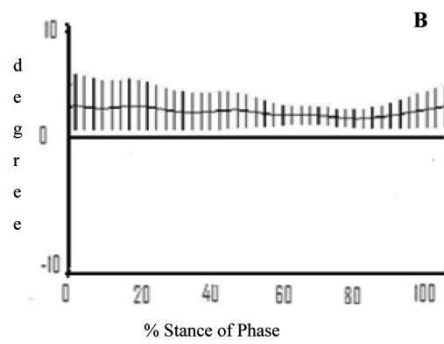


Figure 3. Means and standard deviation of trunk ROM in degree during the stance phase, in BG.

The results show that the trunk were in a distinct position if was OG or BG.

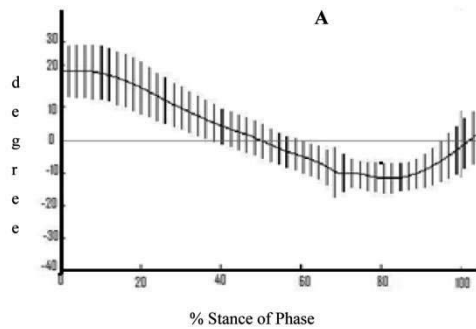


Figure 4. Means and standard deviations of hip ROM in degree, during the stance phase, in OG.

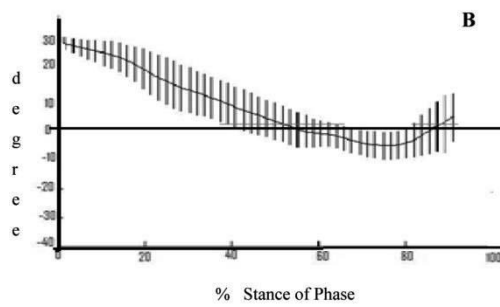


Figure 5. Means and standard deviations of hip ROM in degree, during the stance phase, in BG.

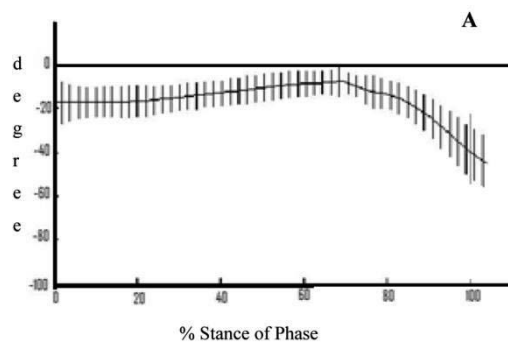


Figure 5. Means and standard deviation of knee ROM in degree, during the stance phase in OG.

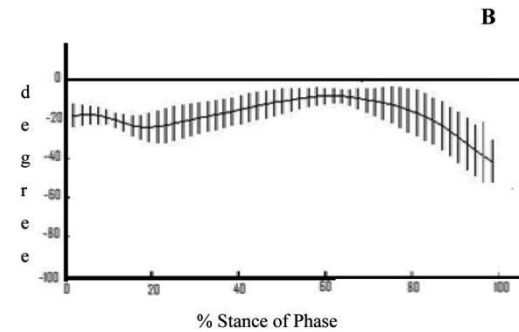


Figure 6. Means and standard deviation of knee ROM in degree, during the stance phase in BG.

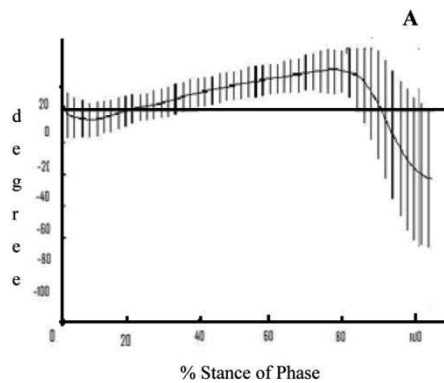


Figure 7. Mean and standard deviation of ankle ROM in degree, during the stance phase in OG.

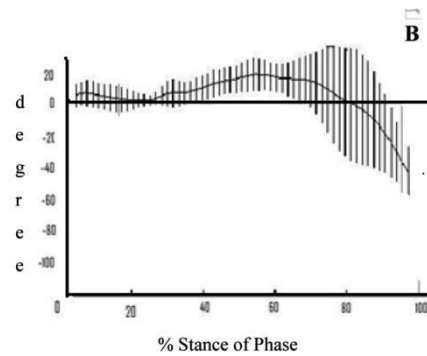


Figure 8. Mean and standard deviation of ankle ROM in degree, during the stance phase in BG.

4. Discussion

The aim of this study is to characterize and compare the gait pattern of adult humans under permanent or occasional overload of the locomotion system. We assumed obese subjects as representative of the first condition, and lean subjects transporting a loaded backpack that roused the “total BMI” up to 30 as representatives of the second condition. Hsiang & Chang et al. (2002) concluded that load and speed can cause changes in gait patterns and in balance. The same was observed by other authors in studies with obese children (Hong and Brueggemann, 2000; Mota and Link, 2001), pregnant women (Lymbery et al., 2005 ; Santos et al., 2008) and individuals who carry loads in backpacks (Birrel & Haslam, 2010; Kinoshita, 1985b; Knapcik & Harman, 1996; Knapick et al., 2004).

In this study, we found differences in the self-selected speed between groups, as well as in other temporal parameters of gait, but also significant dynamometrical and podobarometrical differences in the load response of both groups.

Findings on self-selected speed are consistent with the results of other studies in which obese people freely choose to walk slowly than individuals with normal weight (Dowling et al., 2004; Filippin et al., 2008; Hsiang & Chang, 2002) . Indeed, the OG seems to have reached a kind of adaptation to load that reflects on the temporal parameters of gait, particularly on speed. However, these

temporal parameters do not appear to be sensitive to the presence of load in the BG, perhaps because the load was specifically placed on the backpack, or because this particular sample (active and healthy people) is still able to keep the stability of these components of gait, or the acuteness of the situation did not allow for any adaptation to occur. These late findings were similar to previously published ones. Bezzerra et al. (1999) studied young adults carrying loads of 10, 20 and 30 kg in backpacks, and found great stability of the gait pattern, even during carrying significant loads. Hong and Cheung (2003) also found no changes in the spatial-temporal parameters of gait in children of 9 to 10 years old when the weight of the backpack was about 20% of their body weight.

In this study, the obese group walked at a slower speed (1.08 ms^{-1}) compared to the backpackers group (1.23 ms^{-1}), with implications both in cadence and in stride length – both variables were also higher for the BG. These aspects are surely related to a more time-extended stance phase observed in the OG.

Although backpackers group walked faster than obese individuals in this study, when compared with their pairs of normative weight, they, in fact, walked slowly (cf. chapter 3). Previous studies also evidenced that transporting a backpack decreases the self-selected walking speed and energy expenditure (Abe et al., 2004; Browing & Kram, 2007; Browning et al., 2006).

The reduction in speed causes a decrease in acceleration of the contralateral limb, which will contribute to a decrease in the variation of GRF that can be a strategy adopted to reduce joint stress, and energy expenditure (Dingwell et al., 2001; Mundermann et al., 2004). In accordance to previous literature, the variables that seem to be more sensitive to load magnitude are the vertical and anterior-posterior components of the GRF. In preceding studies, the increase of relative value of GRF intensity was directly related to the load which was applied (Tilbury-Davis and Hooper, 1999; Lloyd and Cooke, 2000; Birrel and Haslam, 2010). Explanation for this effect should be searched on the inter-groups differences in gait speed and because it was an occasional transport of load, which allows subjects to keep the pattern of gait. Indeed, these results cannot be explained by the significant difference found on the mean weight of

the samples ($p = 0.001$). However, the value of the vertical impulse reflects the total capacity of the system to respond to the overload imposed by the task. In our research, the value of this impulse was not significantly different between both groups, which might indicate that, in both cases, the “global burden” had a similar impact on the locomotion system.

These results are consistent with those from studies that compare the gait of backpackers with their pairs of normative weight (Martin and Nelson, 1986; Kinoshita, 1995; Lloyd and Cooke, 2000; Browning and Kram, 2005). Given that the BG was composed of healthy individuals who are active, it was expected that they were less affected by the presence of load.

The time spent in the intermediate stance phase (T_{fzmin}) increased the capacity of the body to resist to external forces at this stage, and may constitute a strategy acquired by individuals submitted to high and permanent loads (Amadio, 1996; Costa, 2000). According to Mota and Link (2001) and Wearing et al. (2006), the increased stance phase duration when an individual carries significant load is due to: (i) the need for stability and dynamic balance maintenance, and (ii) the efforts to reduce the impact exerted over the locomotion system. We can, in some way, infer that obese individuals are more suited with load presence than backpackers.

Analyzing the values of the anterior-posterior GRF component, both the braking (F_{apb}) and the propulsive (F_{app}) peaks showed higher values for the BG, which leads us to suppose that the backpackers are possibly less adapted to load presence, condition translated in high values of impulses. This should, once again, be explained by the different freely-chosen gait speeds. Previous results tended to associate both to absolute value of “total body weight” (Bezerra et al., 1999) Considering the time of occurrence of this event, we suppose that the OG takes longer to perform the braking phase as a strategy adopted to reduce the impact of GRF in the anatomical structures of the lower limb. The horizontal propulsive force was previously found to be higher while walking and carrying a load (Tilbury-Davis and Hooper, 1999; Yanagawa et al., 2004). However, in our particular case, once the OG carries a higher absolute load, differences should once more be searched on self-selected speed. These results are partly in

accordance with those reported by other authors (Kinoshita, 1995; DeVita and Hortobágyi, 2003; Hong and Cheung, 2003; Baker et al., 2006; Browing and Kram, 2007; Leung et al., 2008).

Cavanagh et al. (1991) stated that excessive plantar pressure values are not directly related to body weight, but to the skeletal structure, the variation of the bone anatomy and the pattern of supporting the composition and location of the feet plant where adipose tissue tends to distribute the pressure (Hills et al., 2004).

When comparing the values of plantar pressure between the two groups, the results of our study showed that only small differences were found. There was a trait of higher pressure values at the halux and fingers for the BG and at the midfoot for the OG. Since previous literature points to higher plantar pressure values for obese or extra loaded subjects (Birtane & Tuna, 2004; Burnfield et al., 2004; Gravante et al., 2003; Pau et al., 2011a; Teh et al., 2006) we admit from our results, that this adaptation should be load-type specific.

Recent studies have found that plantar pressure was moderately dependent on body mass index (Gravante et al., 2003; Henning, 2003). Considering our results, we should state that, at least, this variable is not totally dependent on BMI, despite excess mass distribution may play a decisive role on the final profile. Indeed, gait velocity is a factor which may affect the plantar pressures, favoring an increase of the values for higher speeds (Burnfield et al., 2004). The values of plantar pressure in the forefoot were similar between the two groups, which is in accordance with the values of the vertical component of GRF, and also similar between groups at the second peak value, which is consistent with the results of previous studies (Gilmour & Burns, 2001; Riddiford-Harland et al., 2000). The higher values of ROM in the BG at the ankle can contribute to higher values of pressure in these regions.

The values found for the plantar pressure in the forefoot, and trunk position which is further discussed, contradicts the idea that obese individuals move the centre of gravity forward during gait. Other researchers also support this finding (Birtane & Tuna, 2004; Filippin et al., 2008; Wearing et al., 2006).

The fact that the applied load is transient in the BG does not cause the plantar arch swing, implying that BG had less plantar area in contact with the ground compared to the OG, particularly in the midfoot (Deursen, 2004; Hong & Brueggemann, 2000; Nyska et al., 1996a). However, the results of this study pointed out to higher midfoot values for the OG, which forces the recognition of slightly higher values at the forefoot and hindfoot zones during mid-stance for the BG, partially explaining the observed tendency, despite no statistical significance.

The BG showed significant differences in the values of plantar pressure in the halux and other fingers, during the push-off phase, as compared to OG. Once there was no difference at the second vertical GRF peak, the causes of these results may lie on the anatomical structure, the values of ROM at the ankle, and particularly, on walking speed.

Some authors attribute the smaller variation of plantar flexion in individuals exposed to additional loads to a smaller variation of the amplitude of the ROM of the hip joint, the lower step length, and slower speed (Dowling et al., 2004; Harman et al., 2000; Lelas et al., 2003; Mota et al., 2002; Santos et al., 2008; Stansfield et al., 2006b). In our study, we verified higher value of ROM in the ankle, and a lower value in the hip joint. The BG possibly presents these values in the hip joint because the trunk is in the previously conditioned position (flexion). The hip joint functions as a "brake" in the position of the trunk, maintaining greater stability of these individuals during the gait.

Comparing the kinematics of the trunk between obese and backpackers, it was possible to observe that the sway of the trunk was lower in the obese group during the stance phase. In fact, the way load is applied can be crucial to the values found in the trunk kinematics. A more evenly distributed load in the OG can be the reason for looking at a lower ROM of the trunk. In the BG group, load is located at the back side of the trunk, which induces a trunk flexion to bring the centre of mass forward. In this study, it was found that the position of the trunk was different as it were of the OG or the BG. The obese subjects walked with the trunk in extension, while backpackers walked with it in flexion. These results were concurrent with those observed in other studies dedicated to

backpack users (Grimmer et al., 2002; Wang et al., 2001). The load magnitude and characteristics were also crucial for these values. Knapick et al. (1996) found that a load carried in a bag corresponding to 20% of the body weight implies that individuals significantly project their trunk forward. The same was found by Vilas-Boas et al. (2003) for children carrying a load of 30% body weight compared with a load of 15%, or no extra load at all. Other authors, however, pointed out that a backpack loaded at 15 to 25% of body weight can already influence the angle of the trunk (Goh et al., 1998; Song, 2003; Wearing et al., 2006).

That stability is not only determined by the kinematics of the trunk. Also, the hip joint seems to be determinant in these compensatory mechanisms. The results of this study showed that changes in hip joint kinematics in the OG were higher, as compared to the BG. These results were consistent with the observations of other researches (Hong & Cheung, 2003; LaFiandra et al., 2002; Wearing et al., 2006). It is consensual that obesity affects muscle strength (Deforche et al., 2003; Hills & Parker, 1991; LaFortune et al., 2002; Riddiford-Harland et al., 2000). This factor may be the basis of a lower capacity of these individuals to perform a larger knee extension movement when contacting the ground. A reduced extension range of the knee was observed in our study, where a greater ROM (flexion) of individual knee predisposes them to a greater risk of falling (Butler et al., 2006).

5. Conclusion

Both backpackers and obese subjects present very similar gait patterns with some specific load adaptations, but in both cases, they were oriented to reduce the impact of ground reaction forces during the stance phase. Obese subjects prefer a slower walking speed, which can explain the reduced GRF values and plantar pressures, with the exception of the midfoot region. In this particular finding, it is not possible to exclude any influence of the anatomical structure of the foot.

The values of plantar pressure in the halux and other fingers were higher in the backpackers group. This is possibly due to the higher freely-chosen gait speed and the higher ROM of the ankle.

While the obese subjects walked with a more upright posture, the backpackers walked over with the trunk flexed forward. This strategy possibly aims to maintain stability and balance during gait considering the particular position of the extra load.

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Chapter 5

Original Research

**Anterior-posterior regional and global shear stress
during loaded gait: backpackers vs. obese people**

Abstract

Among the mechanical factors that cause foot lesions, shear stresses have been either neglected or underestimated. The purpose of this study was to establish whether the individuals were submitted to load were more predisposed to shear forces than individual's normative weight.

One recorded the vertical and anterior-posterior ground reaction forces (GRF) by a force plate, the plantar pressure by a insole pressure system, of 20 healthy obese (body mass index (BMI) = 37.70 ± 4.70) and 11 lean people (BMI = 23.4 ± 6.03) during self-selected gait speed.

The results were different if was absolute or normalized shear force, but the hindfoot central and the halux showed statically significant difference between the two situations. The value of absolute shear force in the hindfoot was significantly different in the central region between the obese and control group ($p=0.044$), and in the forefoot lateral and halux we observed significant differences between all the three groups studied, ($p=0.001$ and $p=0.046$, respectively). Analyzing the values between the groups the lateral forefoot provides statistically significant differences between OG and CG ($p = 0.027$ and $p = 0.021$, respectively), the same is observed for the halux, ($p = 0.001$).

The normalized shear force showed statically significant difference in the hindfoot central and halux in all groups studied. Analyzing the values between the groups, the hindfoot central and medial provides differences between the BG and CG ($p=0.043$ and $p=0.058$, respectively), the hindfoot central show statically difference between the OG and CG ($p=0.014$).

Between OG and BG groups was significantly differences in the forefoot lateral ($p= 0.035$) and in the medial ($p=0.004$). Statistically significant differences were found between OG and CG in halux ($p=0.004$) and between OG and BG ($p=0.001$).

The hinfot central was one of the foot areas subject to shear stress potentially lesion's inducer. Considering the values of the backpackers and obese this groups have greater predisposition to shear injuries in the hindfoot central, the forefoot lateral and halux.

Key Words: obesity, backpackers, shears forces, plantar pressure, coefficient of friction.

1. Introduction

The foot is the most important structure of weight bearing and shock absorption of the human body (Henning, 2003). The presence of overload affects the gait pattern making the foot more susceptible to biomechanical changes (Deursen, 2004; DeVita & Hortobágyi, 2003; Seung-Uk et al., 2010; Spyropoulos et al., 1991).

According to the Physical Stress Theory as a theoretical background, the key stress variables that contribute to skin injury on the plantar surface of the foot would include the intensity, time, and direction of stresses (Mueller et al., 2008b; Mueller et al., 2005) .

The primary directions of stress application generally are thought of as perpendicular or parallel to the skin surface. The measurement of shear forces has been particularly difficult to obtain (Lord & Hosein, 2000). Due to this difficulty, different models have been developed to best estimate these values (Hosein & Lord, 2000; Lord et al., 1992; Yavuz et al., 2007c). Given the difficulty in measuring the shear forces, several articles have established models to predict shear stress under the foot. Abuzzahab et al. (1997) proposed to estimate shear distribution, based on local pressure data and global ground reaction forces. Their aim was to create a kinetic model of the foot and the ankle where they distributed shear loads to each segment of the foot based on the arithmetic contribution of the local normal forces to the global vertical force. In the previous plantar shear studies, peak shear stress values were chosen as the major indicative parameter, similarly to what happened in the pressure studies (Lord & Hosein, 2000).

Plantar shear stress distribution depends on local frictional properties of the sole, gait velocity, and, most likely, the internal muscle activity (Bus et al., 2002; Yavuz et al., 2007a). There is, however, limited epidemiological research on

injuries and illnesses associated with soft tissue wounds such as blisters, especially in obese individuals and backpackers.

Identified this gap in the literature, our objective was to establish whether the individuals when subjected to load were more predisposed to shear forces than individual's normative weight.

2. Methodology

2.1. Participants

The sample was selected by convenience. As inclusion criteria the participants should be aged between 46-70 years old and have body mass index (BMI) ≤ 25 (control group - CG) or $\geq 30 \text{ Kg/m}^2$ (obese group – OG and backpackers group – BG). The exclusion criteria were any disturbance of balance, musculoskeletal dysfunction or any difficulties in independent locomotion. Thus, 31 participants were enrolled in this study, 9 women and 11 men for the OG, 4 women and 7 men for the CG. The CG had a mean age of 47.55 ± 14.60 years, and height of $1.62 \pm 0.08 \text{ m}$, a weight of $613.81 \pm 8.49 \text{ N}$ and the BMI of $23.4 \pm 6.03 \text{ Kg/m}^2$. The CG, when loaded with a backpack that imposed a “total BMI” of 30 Kg/m^2 , constituted the backpackers group (BG). The OG present an average age of 57.90 ± 7.90 years, an height of $1.61 \pm 0.08 \text{ m}$, a weight of $945.90 \pm 11.40 \text{ N}$ and the BMI of $37.70 \pm 4.70 \text{ Kg/m}^2$.

The CG was composed by college officials and the OG also by college officials and patients from the sleep apnea service of a local hospital, the patients were with the sleep apnea controlled and in good health.

2.2. Instruments

A Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA) operating at 1000 Hz, a Bertec amplifier signals system (model AM 6300, Bertec Corporation, Columbus, USA) and a Biopac analog-digital converter (Biopac System, California, USA), were used for ground reaction forces (GRF)

assessment. To allow monitoring the plantar pressure distribution, a insole podobarometric system Pedar (Novel, Munich, Germany) was used.

2.3. Procedures

The study was approved by the local ethics committee and all participants freely signed an informed consent term that explained the procedures to be performed and the study purposes.

The participants used neutral shoes (similar to ballet shoes) with a pressure insole inside. After a brief adaptation, it was asked to all participants to walk over a 6 m walkway, at a self-selected speed.

So, the researcher verified what should be the most adequate position in which the participants should start walking in order to trample the force plate so they should start the gait with their right foot without changes their gait pattern. The plate was positioned at the middle of the walkway. Three valid tests were recorded.

For each participant of the CG, the weight needed to raise their BMI to 30 kg/m^2 was calculated, and then a backpack was filled with sand and fixed in the central area of each subject's back. The mass placed inside the backpack ranged from 11.2 to 20.7 kg (mean weight $17.7 \pm 2.9 \text{ kg}$). This overload was chosen because it is considered to leave the locomotor system more susceptible to injuries (Ko et al., 2010).

For the acquisition of the force plate data the *Acknowledge (BIOPAC System, California, USA)* software was used. These data were exported to Matlab 7.0 (MathWorks, Massachuets, USA) in which a program was developed to the processing and calculation of the variables: the horizontal anterior-posterior ground reaction force (GRF) component breaking (negative) peak (F_{apb}) and the propulsive (positive) peak (F_{app}) of the same GRF component.

To analyze the plantar pressures, the foot was divided into 10 regions, as suggested and adapted from previous studies (Cavanagh & Ulbrecht, 1994; Gurney et al., 2008a). We consider the absolute and body weight normalized values of plantar pressure in the different areas of foot. The boundary between

the hindfoot and midfoot was located 73% of the foot length (from toes to heel direction) being the hindfoot divided into three equal parts (33% each). The boundary between the midfoot and forefoot was located 45% along this length being the midfoot divided into two equal parts (50% each). The forefoot was divided into three regions being 30% medial (first metatarsal region), 25% central (second metatarsal region) and 45% lateral (lateral metatarsals region), and the region of halux. We analysed the hindfoot in the braking phase, and the forefoot and halux in the propulsive phase.

To compute the shear stress the relative value of plantar pressure in the studied foot areas and the values of the anterior-posterior GRF component (F_{ap}) during the braking and the propulsion phases were taken.

Considering the total (P_T) value of plantar pressure as:

$$P_T = P_1 + P_2 + P_3 + \dots,$$

where P_1 , P_2 , P_3 ... corresponds to the plantar pressure in each one of the defined plantar areas of the foot.

The percentage of P_T for each plantar area (P_{area}) was calculated as follows:

$$\% P_{area} = (P_{area} / P_T) * 100$$

Based on the percent distribution of plantar pressure per plantar area, the anterior-posterior horizontal component of the GRF was also distributed, and considered to be a marker of shear stress exerted over each plantar zone:

$$\% F_{ap_area} = (\% P_{area} * F_{ap_m\acute{a}x (area\ foot)}) * 100$$

3. Statistical Analysis

The normality of the data was verified using Shapiro-Wilk test and the homogeneity of the variances using Levene's test.

In order to meet the assumptions of normality (Kolmogorov–Smirnov test) and homogeneity of variances (Levene's test) of the variables due in the form of a transformation of the variables ($10\log x$) of plantar pressures of hindfoot (medial, lateral and central), forefoot (medial, lateral and central) and halux.

Statistical analysis was performed using the descriptive statistics for sample description; a linear model of multivariate repetitions (MANOVA) was also used to analyze the differences between the values of plantar pressure in the various groups and make comparisons between them, followed by the post-hoc HSD test of Tukey. The data relating to the average and standard deviation were turned back at the original measures.

All analyses were conducted in the SPSS software (v.17; SPSS Inc, Chicago, IL, USA) to a level of significance (α) of 0.05.

4. Results

Table 1 shows the absolute values of shear anterior–posterior forces estimated for the three groups.

The comparison between the three groups, and the interaction analyzed between the presence of load and the values of plantar pressure are presented in table 1. The results showed no significant interaction effect between the presence of load and the plantar pressure values in hindfoot medial ($F_{(1,72)}=0.969$; $p=0.389$; $\eta^2=0.049$); central ($F_{(1,72)}=3.130$; $p=0.555$; $\eta^2=0.141$) and lateral ($F_{(1,72)}=0.277$; $p=0.759$; $\eta^2=0.014$).

Table 1. The mean (and standard deviation) values for the absolute anterior-posterior shear forces in the medial, central and lateral hindfoot regions, during the braking phase.

	Groups			ANOVA			
	OG	CG	BG	F	P	Size effect (η^2)	Power
hind_med	32.76 (14.38)	28.12 (7.831)	25.17 (17.13)	0.96	0.38	0.04	0.20
hind_cent	38.64 (14.56)	26.35(13.53)	25.93 (19.67)	3.13	0.55	0.14	0.57
hind_lat	32.83 (16.45)	32.01(10.90)	25.39 (22.25)	0.27	0.75	0.01	0.09

hind_med(medial hindfoot);hind_cent (central hindfoot); hind_lat (lateral hindfoot). * Significant interaction effect at $p < 0,05$

After completion of the post-hoc test, we found that data showed significant differences between obese and control groups in plantar pressure, but only in the region of the central hindfoot ($p = 0.044$).

In table 2 significant interaction effects are showed between the presence of load and the plantar pressure values in the forefoot medial ($F_{(1.72)}=2.681$; $p=0.081$; $\eta^2=0.124$); central ($F_{(1.72)}=1.458$; $p=0.246$; $\eta^2= 0.071$); lateral ($F_{(1.72)}=9.356$; $p=0.001$; $\eta^2= 0.330$) and halux ($F_{(1.72)}=3.34$; $p=0.046$; $\eta^2= 0.149$).

Table 2. The mean (and standard deviation) values for the anterior-posterior shear forces (absolute) in the central, lateral and medial forefoot region during the propulsive phase.

	Groups			ANOVA			
	Obese	Control	Backpackers	F	P	Size effect (η^2)	Power
forefoot_med	23.81 (6.85)	18.96 (7.06)	24.49 (6.99)	2.68	0.08	0.12	0.50
forefoot_cent	28.17 (2.46)	29.07 (10.40)	26.33 (6.99)	1.45	0.24	0.07	0.29
forefoot_lat	27.89 (7.26)	20.03 (4.79)	14.48 (8.36)*	9.35	0.00*	0.33	0.96
Halux	20.11 (5.90)	31.91 (8.74)	34.67 (13.92)*	3.33	0.04*	0.14	0.59

forefoot_med (forefoot medial); forefoot_cent (forefoot central); forefoot_lat (forefoot lateral)

* Significant interaction effect at $p < 0, 05$

After completion of the post-hoc test, we observed the following results the obese group differ statistically in comparison to the control group, during the propulsive phase, in the mean values of plantar pressure on the medial and lateral forefoot ($p=0.027$; $p=0.021$; respectively) and halux ($p=0.001$).

The backpackers showed significant differences in comparison to the obese group in the forefoot lateral ($p=0.001$) and in the halux, $p=0.027$.

In table 3 the results of the normalized values of anterior-posterior shear forces, during the braking phase, are presented.

The results showed significant interaction effect between the presence of load and the plantar pressure values in variables in hindfoot medial ($F_{(3.19)}=2.220$; $p=0.122$; $\eta^2=0.100$); central ($F_{(3.19)}=3.367$; $p=0.045$; $\eta^2=0.141$); lateral ($F_{(3.19)}=1.138$; $p=0.331$; $\eta^2=0.052$).

Table 3. The mean (and standard deviation) values of the results obtained from anterior-posterior shear forces (normalized) in the central, lateral and medial hindfoot region during the braking phase.

	Groups			ANOVA			
	Obese	Control	Backpackers	F	P	Size effect (η^2)	Power
hind_med	9.74 (0.43)	9.47 (0.34)	9.90 (0.56)	2.22	0.12	0.10	0.42
hind_cent	4.35 (0.11)	4.23 (0.13)	4.34 (0.13)*	3.36	0.04*	0.14	0.62
hind_lat	4.30 (0.12)	4.36 (0.13)	4.25 (0.23)	1.13	0.33	0.05	0.23

hind_med (medial hindfoot); hind_cent (central hindfoot); hind_lat (lateral hindfoot). * Significant interaction effect at $p \leq 0.05$

Comparing the groups together to look at whether there are differences in the values of plantar pressure in the braking phase in the hindfoot.

The backpackers group differ significantly from the control group in medial and central hindfoot ($p=0.043$; $p=0.058$, respectively), and the obese group showed significant differences in comparison to the control group in the hindfoot central ($p=0.014$).

The results presented in table 4 show the interaction effect between the presence of load and the plantar pressure values in the forefoot medial ($F_{(2.05)}=1.968$; $p=0.152$; $\eta^2=0.127$); central ($F_{(2.05)}=2.471$; $p=0.097$; $\eta^2=0.079$);

lateral ($F_{(2.05)}=2.887$; $p=0.067$; $\eta^2=0.329$) and halux ($F_{(2.05)}=12.232$; $p=0.001$; $\eta^2=0.157$).

Table 4. The mean (and standard deviation) values obtained for the anterior-posterior shear forces (normalized) in the central, lateral and medial forefoot region and halux during the propulsive phase.

	Groups			ANOVA			
	Obese	Control	Backpackers	F	P	Size effect (η^2)	Power
forefoot_med	1.72 (6.87)	1.19 (4.22)	1.41 (9.27)	1.96	0.15	0.12	0.38
forefoot_cent	2.08 (5.61)	1.52 (8.17)	1.81 (7.64)	2.47	0.09	0.07	0.46
forefoot_lat	1.98 (9.49)	1.61 (1.29)	1.17 (5.55)	2.88	0.06	0.32	0.53
Halux	5.62 (3.08)	1.23 (5.26)	1.51 (9.18)*	12.23	0.00*	0.15	0.99

forefoot_med (forefoot medial); forefoot_cent (forefoot central); forefoot_lat (forefoot lateral). * Significant interaction effect at $p < 0, 05$

The backpackers group differ significantly in comparison to the control group in medial forefoot ($p=0.004$) and with the obese group in the lateral forefoot ($p=0.021$).

The obese group showed significantly different values in comparison to the control group in the central forefoot ($p=0.035$). At the halux differences were observed between obese and the other two groups: control and the backpackers ($p=0.004$; $p=0.001$, respectively).

5. Discussion

The purpose of this research was to establish whether individuals submitted to load are more prone to shear lesions than individuals of normative weight.

The effect of plantar pressure during gait is not fully understood. Therefore, there is a need to study normal and pathological subjects to know the exact values of peak pressure on the plantar surface, capable of causing tissue damage (Rai & Aggarwal, 2006).

Even if the perspective is narrowed to physical stresses alone, there are several characteristics of physical stresses that could contribute to skin injury and breakdown (Mueller et al., 2008b; Smith et al., 2000).

Shear forces exerted over the plantar surface of the human foot are thought to be responsible for various foot pathologies such as diabetic plantar ulcers and athletic blisters. Shear combined with pressure has also been associated with ulcer incidences (Bowling et al., 2011; Lord & Hosein, 2000; Yavuz et al., 2007a).

Perhaps the plantar pressure is an important indicator of tissue trauma because it indicates high levels of stress concentration in the soft tissues that may lead to skin breakdown (Caselli et al., 2002a; Mueller et al., 2005). Indeed, the measurement of foot pressure's distribution has constituted one of the good predictors for the appearance of lesions, particularly in individuals with diabetes (Cavanagh et al., 2000). It turns out that most of the injuries due to foot shear appear in regions that are submitted to higher pressures. According to Pollard & Quesne (1983) the study of the forces acting on the sole of the foot showed that these ulcers occur at the site of maximal horizontal shear force and confirmed that they occur at the same site of the maximal vertical force.

As to the pressure studies, in the previous plantar shear researches, peak shear stress values were chosen as the major indicative parameter (Lord & Hosein, 2000; Lott et al., 2008; Yavu et al., 2008). Some authors have attempted to relate the values of this variable with the appearance of lesions in the foot, but this correlation was found to be only moderate (Hessert et al., 2005; Leeden et al., 2005; Yavuz et al., 2007c).

Depending on whether normalized or absolute values are considered, we observed different areas of the foot submitted to significantly higher values of shear force in loading situations compared to controls. These results can be attributed to the specific load and to the specific gait pattern adopted by each of these groups. Indeed, different investigations were already able to show that load is susceptible to change the gait pattern of humans (DeVita & Hortobágyi, 2003; Perry, 1992; Spyropoulos et al., 1991).

During the braking phase we observed the hindfoot medial and central are always submitted to higher shear stress in the loaded groups: obese and backpackers. These results were possibly due to the way the backpackers

walked. Their gait pattern seems to protect less this area of the foot, causing high peaks of plantar pressure.

In a previous (chapter 4) we observed that the gait pattern recruited by BG and OG presents higher values of F_{z2} (normalized). In the literature it is known that higher values of this component also cause higher values of plantar pressure.

In a previous study the gait speed (chapter 3) may have had some influence on the results of plantar pressure obtained in BG. Indeed in our work this sample showed a value of self- selected, very similar to the control group value. In fact the speed increase causes higher values of plantar pressure (Segal et al., 2004; Taylor et al., 2004a).

The results showed that the foot to the OG and BG target groups should have a greater attention because high values of plantar pressure have been associated with the appearance of injuries, particularly in pathological conditions (Bacarin et al., 2009 ; Höhne et al., 2009; Oh-Yun & Mueller, 2001; Rai & Aggarwal, 2006).

Given these results we can infer the hindfoot medial and the central region of the foot may be more liable to injuries in the individual's submitted to load. From the studies consulted we did not find any that makes a division of hindfoot in three regions, limiting comparisons with our results.

The vast majority of the previous studies on this issue are very focused on diabetic foot problematic. In these particular case, the areas more predisposed to this type of injury are the forefoot and the halux (Gefen et al., 2010). The hindfoot is least prone, being this discrepancy explained by the fact that this plantar foot area is more cushioned (Caselli et al., 2002b; Mueller et al., 2008b). The gradient of plantar pressure may be a useful indicator of skin trauma because spatial changes in high plantar pressures may identify high stress concentrations within the soft tissue (Mueller et al., 2005).

As what was observed in the hindfoot, in forefoot and halux we realized the areas in which are present higher stress values differ, depending on whether the absolute or normalized values, are considered. There is a similar gait pattern in the two conditions (values normalized/absolute) indicating a tendency to overload in the forefoot (lateral and medial) and the halux. These

were more predisposed to higher values of shear forces, particularly in the obese and backpackers groups.

The lower mobility of the lower limb joint observed in OG and BG can be a plausible explanation to the higher values of plantar pressure. These aspects can somehow explain higher values in this region of the foot for these groups.

In studies with the diabetic population, the individuals who had higher values of plantar pressure (and consequent appearance of blisters) were the ones who had less joint range of motion (Lord & Hosein, 2000; Yavu et al., 2008). On the other hand, the forefoot showed a smaller contact area that decreases the absorption capacity of forces. In fact the most studies state that the presence of load increases the plantar pressure values in these areas of the foot (Birtane & Tuna, 2004; Burnfield et al., 2004; Dowling et al., 2001; Mueller et al., 2005; Pau et al., 2011b; Rai & Aggarwal, 2006).

Mueller et al. (2008a) indicated that the plantar pressure is much higher in the forefoot than in the hindfoot (high forefoot-to-hindfoot ratio). These results may be important because the incidence of skin breakdown is much higher in the forefoot than in the hindfoot. Similar results have also been found by Caselli et al. (2002a).

According to Gooding et al. (1986) there are a number of reasons why the forefoot may experience higher stress values than the hindfoot. First, soft tissue is about 36% to 48% greater in the hindfoot than in the forefoot. This way we understand that the soft tissue plays an important role in stress distribution. The thicker tissue under the hindfoot compared with the forefoot may help to distribute stresses evenly to the underlying bony structures. Indeed it's often highlighted the structural behavior of the human heel pad due to its ability to absorb shocks, protecting against excessive local stress and reduce plantar pressures (Miller-Younga et al., 2002).

On the other hand, and according to Pau et al (2011b), the backpack introduces significant increases in the overall contact area (up to 10%) and in the plantar pressure peaks in midfoot and forefoot regions (20-30%). Conversely our results indicate that the BG displays values of significant shear forces in the

anterior region of foot (forefoot and halux), but it didn't provide any evidence of increased contact area due to load.

High stress values occur at the hindfoot and forefoot during at heel-strike and push-off, respectively, because body-weight forces are focused on a relatively small area of the foot compared with forces during midstance, when the entire foot is in contact with the ground (Mueller et al., 2008b; Mueller et al., 2005).

These studies validate, in part, our results, in which forefoot and halux present high values of foot plantar pressure. Relating the values of this variable with the development of blisters, it should be given a special attention to these areas in individuals submitted to occasional or permanent load, allowing the prevention of injuries.

For the obese population, walking is the type of exercise recommended to treat this health condition. As a consequence, it is essential to prevent the appearance of this type of injury, which may compromise their adherence to this physical activity. Prevention can pass by the construction of an ortotese that minimize the appearance of these injuries.

6. Conclusion

Given the difficulty in evaluating the shear force, the higher values of plantar pressure appear to be an appropriate means to infer the risk of emergence of shear-induced injuries.

It was possible to observe that the hindfoot was less likely to shear injury. However, the central hindfoot seems to be a zone to take into consideration in groups submitted to load.

There seems to be a predisposition for the appearance of blister compared to individuals not subject to load.

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Chapter 6

Synthesis, Final Conclusions and Future Work

The purpose of this work was to characterize the overloaded gait regarding its biomechanical aspects in individual adults.

The available literature underlined that there were several researches that addressed the study of gait in this condition, but in very specific populations such as obese children, pregnant women and military. These populations have special characteristics, reason why we intent to characterize the gait of not so specific subjects submitted to load, like obese adults and backpackers. We chose these two groups because we hypothesised that the nature of load (permanent or occasional) might have distinct impacts on gait, both due to masses distribution and also due to adaptation processes.

We did not find any studies that searched for an integrated approach to kinematic and kinetic (dynamometrical and podobarometrical) components of overload gait biomechanics. This overall approach (GRF plus plantar pressure and kinematics) on gait structure may help in the development of some strategies to prevent injuries and implement higher performance capacities in this particular activity.

On the other hand, we also checked the absence of studies that compare permanent and occasional loaded conditions. From our perspective, this makes it difficult to understand what the impact of a given situation has on the gait.

So, we focused our study in two distinct situations in presence of load during locomotion: the permanent (obese) and the occasional (users of backpacks) conditions.

As it was expected from previous literature (Browning & Kram, 2007; Cham & Redfern, 2004; Cottalorda et al., 2003; Fabris et al., 2005; Wearing et al., 2006), gait pattern seems to be influenced by overload in GRF, plantar pressure parameters, and temporal gait events, independently of the occasional or permanent nature of load.

In our studies, the obese individuals and backpackers had generally higher absolute values of GRF compared to controls. This had implications for their gait pattern when compared to their peers with normative weight while walking at a self-selected speed. Our results were consistent with other studies based

on the gait in individuals submitted to load conditions (Chow et al., 2006; Hsiang & Chang, 2002; Sacco et al., 2001; Seung-Uk et al., 2010).

With regard to GRF values, these were, on average, more expressive in certain parameters: in the first vertical peak, in the intermediate minimum and in the second vertical peak.

The relative values of GRF in the first vertical peak did not demonstrate a significant difference when the two load's type groups and the control group were compared. This relates to a better control of the distribution of the forces during gait, in order to mitigate the impact, and protecting the passive locomotor structures involved in this mechanism of mechanical shock absorption.

The GRF values observed in these groups were probably conditioned by the values of the self-selected gait speed. It's known that the choice of gait speed is associated with comfort sense (Bertram & Ruina, 2001). The slower rate adopted by loaded subjects was eventually an acquired strategy to reduce the impact of these forces in the locomotors system. This aspect has already been shown in other studies of obese children, backpackers and pregnant women (Attwells et al., 2007; Jordan et al., 2007; Lloyd & Cooke, 2000; Santos et al., 2008).

We found that both obese individuals and backpackers had the highest values in peak braking force of the anterior-posterior GRF component compared with the control group. The braking peak has been connected to the weight applied on the foot. It shows a slight tendency to increase in magnitude with increased body weight. Similar results to those were obtained in other studies which confirmed a similar variation of this parameter (Bezerra et al., 1999).

The braking impulse had a greater positive relationship with walking speed (Peterson et al., 2011); in our studies (appendix 1), the groups submitted to load walked at a lower speed than the control group, the greater braking time was possibly a strategy adopted to reduce the impact of GRF in the anatomical structures of the lower limb.

Considering the propulsion force, we were able to observe it is higher mean values in BG and OG compared to the CG, findings that were consistent with those from other authors (Browing & Kram, 2007; Terrier, 2003). At this stage

the individuals have to apply an adequate force to shift their bodies (and its centre of mass) forward. Given the BMI of this sample, it's apparent that both obese individuals and backpackers will have to develop a higher force compared to normative weight counterparts.

Relatively to controls, the values of vertical impulse were significantly higher in the groups submitted to load (both obese and backpackers), and non-significant difference was found between them. The high values of vertical impulse in these groups are both due to the load itself, but mostly (once the relative values of GRF were lower) to the longer stance phase that characterizes their walking pattern, as already observed by other authors in loaded subjects (Birrel et al., 2007; Hong & Brueggemann, 2000; Oberg et al., 1994; Santos et al., 2005). Indeed, the adoption of a slower gait by the loaded subjects has, as a consequence, a decrease of the GRF relative intensity. The more time spent in the support phase is advantageous due to the viscoelastic properties of tissues, which allow for a better adaptation.

However, the increased stance phase implies greater values of vertical impulse, thus the locomotor system will be submitted to this load over time. The permanence of this force can cause damage to the musculoskeletal system. These results were consistent with other studies involving the transport of additional loads (Birrel et al., 2007; Hong & Brueggemann, 2000; Lymbery et al., 2005 ; Oberg et al., 1994).

Within the larger project that includes this thesis, there was a study with backpack users (Castro et al, 2011), whose purpose was to investigate the effect of speed on the value of the impulse of the vertical force. Results suggested that the backpackers, walking with a slower speed, were submitted to a higher total mechanical load (impulse) and a lesser mean vertical force when compared to fast gait. Another study developed by us (appendix 2), with a sample of young backpacker (age between 18 and 45 years), we also observed a longer stance phase compared to the control group. Therefore, the backpacker has more time (larger duration of stance phase) to dissipate force during slow gait, making this activity more comfortable.

Accordingly, the spatial-temporal parameters of the gait cycle are altered in both groups. Speed, cadence and step length were of lesser magnitude in groups submitted to load comparing to individuals of normative weight (controls). These results are consistent with those found in other studies, performed in populations with similar characteristics (Abe et al., 2004; DeVita & Hortobágyi, 2003; Griffin et al., 2003; Hills et al., 2002b; Knapick et al., 1999a; Knapick et al., 2004; Nantel et al., 2011; Wearing et al., 2006).

These values have conditioned the GRF and plantar pressure values. Individuals who are subjected to overload, walk more slowly, with smaller ROM in almost all joints this "choose" this form of walking in order to minimize the impact of the forces to which they are subject. In fact a gait more "dragged", with small steps increased the supporting of foot and the contact area, causing lower values of plantar pressure (Brown & Mueller, 1998). This way to walk implies a lower ankle ROM by decreasing the time of toe-off and contributes to lower values of plantar pressure (Zhua et al., 1995). These strategies allow a lower metabolic cost, allowing for greater efficiency in the execution of this activity.

The slower rate adopted by obese individuals and backpackers were eventually an acquired strategy to control the increase of load during the load-acceptance and the propulsion phases. In fact, the reduction of the relative values of the first and second peaks of vertical GRF component for the overload conditions obtained in our study, combined with the increase stance phase, seems to be a way to protect the biomechanical system.

The increased time duration of the stance phase when an individual carries significant loads is due to the need of maintaining the stability and dynamic balance during gait, and on the other hand, to reduce the impact on the loco motor system (Mota & Link, 2001; Santos et al., 2008; Wearing et al., 2006).

The magnitude of plantar pressure can provide useful information to diagnose the various foot disorders (Cade, 2008; Mueller et al., 2008b; Mueller et al., 2005). In our study, the plantar pressure values were different depending on the group studied. For the obese group, the plantar pressure values were lower in all regions of the foot except the mid foot. The most plausible reasons for these

findings are the presence of morphological and functional changes in the structure of the foot of the obese, where a plausible arc folding may play a central role. Several authors have pointed out that the plantar arch flattening has an observable change in the vast majority of obese individuals, which contributes to the lowest values of plantar pressure (Caravaggi et al., 2010; Filippin et al., 2008; Karadag-Saygi et al., 2010b; Ribas & Guirro, 2007a; Ribeiro et al., 2011; Santos, 2005; Wearing et al., 2004). However, the highest values of plantar pressures in mid foot, observed in obese subjects during the weight acceptance phase, should simply result from the greater load exerted over the foot. A flatter plantar arch would only reduce those pressures by spreading the effort for a larger contact area. Instead, the lower values of plantar pressure in the other areas of the foot may be associated with the lower gait speed, cadence, and step length and from the normalized values of the GRF (Fernando et al., 1991; Reiber et al., 1999; Zimny et al., 2004).

Of all the groups studied, the BG is one that displays higher values of plantar pressure. In another study conducted by us, with a younger sample, we observed similar results (appendix 3). Foot areas with higher values are in the forefoot, halux and other toes. We believed that these results could be explained by the fact that all these foot regions have little cushions and therefore made them more difficult to adapt to the extra weight condition. Taking into account the aspects of the trunk position (due to the applied load in the back), it can partially justify the higher plantar pressure values in these anterior areas of the foot.

Differences in the self-selected speed may also have influenced the results of the pressure distribution, since walking at a higher speed imposes higher force and, normally, also higher pressure values (Burnfield et al., 2004; Perttunen & Komi, 2001; Taylor et al., 2004b).

Our results were analogous to other studies in similar populations (Crenshaw, 2004; Gaymer et al., 2009; Hoboni et al., 2002; Karadag-Saygi et al., 2010a; McGraw et al., 2000; Ribeiro et al., 2011; Rossum et al.). The fact that the values in plantar pressure were higher in the backpackers compared to the other groups (controls and obese), may reflect a kind of maladjustment to the

acute loading, and can increase the risk of foot discomfort in these subjects, leading to the appearance of blisters (Dowling et al., 2001; Knapick et al., 1999a).

Joint kinematics was also sensitive to the presence of load during locomotion. In fact, we observed differences in the ROM in BG and in the OG comparatively to the control group. These variables were also different when obese and backpackers were compared. The major difference between the groups carrying loads was observed in the ROM of the trunk. While obese and control group walked with an erect posture, backpackers, instead, took a tilted position, in flexion. Also previous researches indicated that backpack loads caused biomechanical changes including forward inclination of the trunk (Hong & Brueggemann, 2000; Li, 2001; Shasmin, 2007; Souza, 2005).

DeVita and Hortobagyi (2003) opinioned that obese adults tend to assume a more erect posture while walking at a standard speed. It is widely noted that walking in a more erect posture promotes greater stability and lower energy costs.

In the hip joint the backpackers and obese group presented lower values of the ROM during the gait cycle, a fact which probably contributes to the maintenance of stability and balance when walking. Various studies stated that the maximum hip angle decreased the likelihood of improving stability and reduce stress on the musculoskeletal system (DeVita & Hortobágyi, 2003; World. et al., 2000). However, the ROM of the knee in OG and BG are virtually equal to the one recorded for the normative weight group. This possibly happens to minimize the impact of the various forces that the lower limb is submitted to during the gait. According to some authors, the impact of GRF can be minimized by the higher ROM of the knee (Browing & Kram, 2007; Lelas et al., 2003). Perhaps because of this condition there is a higher prevalence of osteoarthritis in the knee in the obese population (Cooper et al., 2000; Grotle et al., 2008; Reijman et al., 2007; Vasconcelos et al., 2008; Woolf et al., 2006).

The ROM of the ankle in the obese group showed lower values comparatively to the backpackers and control groups. This result may be due to lower values of the peak vertical GRF. Nonetheless, this condition was verified in other

researches (Giles-Corti, 2003; Lee et al., 2009b). The amplitude values observed in the ankle joint are possibly related to the values found in the hip. Some studies indicate that the decrease in hip ROM influences the values of the foot (Birrell & Haslam, 2009; Hansen, 2002; Lelas et al., 2003; Malouin & Richards, 2000; Nymark et al., 2005; Stansfield et al., 2006a).

The ROM of the ankle joint in the backpacker's group is still very similar to that seen in the control group. Once again, this might be a consequence of the acuteness of the loading situation, not allowing sufficient time for the subject's adaptation to load.

In the last research that we conducted and reported in this thesis, it was our goal to identify if the obese individuals and backpackers would be submitted to the higher values of shear force which can make them prone to shear injuries (such as blisters). In this work, we assumed that the maximum peak of plantar pressure, normalized to the anterior-posterior component of the GRF, could constitute an indicator of potential tissue injury. It was possible to see that the regions more predisposed to this type of injury were different if the absolute values of shear forces were considered or, instead, those normalized to body weight. It was also possible to identify areas in common with both of these situations, and those are the ones that should be considered more liable to injury: the central hindfoot, the central forefoot and the halux. This predisposition was higher in the group of backpackers. These results may be due to the lower thickness of cushioning in the foot of subjects not systematically submitted to load.

The gait today is one of the most popular activities for prevention/ treatment of many clinical situations. In the case of obesity, the gait is part of the treating for this epidemic. We know that the obese individuals normally have a sedentary behavior. If activity is not carried out in a comfortable way, adherence to on the part of the population will be very scarce.

From the knowledge attained, we can develop some strategies to promote this activity. Making an orthotics that prevents the emergence of this type of injury can, for instance, allow this activity to be more comfortable.

Final Conclusions

The presence of load has potential impact on the musculoskeletal system, both in permanent and in circumstantial conditions.

Obesity causes a situation of permanent overload with potentially adverse effects on the musculoskeletal system. The occasional overload also impacts on the walking cycle structure and the integrity of tissues, but differently from obese subjects.

These differences between the two conditions are:

- The obese individuals exhibit a gait pattern with changes in the spatio-temporal variables in order to diminish the impact of the forces to which they are submitted during the gait. These changes constitute a locomotor system protection, allowing these individuals to perform this basic of day-by-day activity efficiently. Possibly these strategies are developed throughout life to be functional in its various tasks. Note that obese individuals have values of range of motion similar to individuals of normative weight, reason why these individuals are more predisposed to osteoarthritis in this articulation.
- The backpackers alter their gait pattern in order to minimize the impact of the burden imposed on it. Notice, however, that these individuals retain their gait pattern very similar to that held without load, possibly because it is a temporary overload allowing not sufficient time to occur an adaptation. We believe that these individuals do not feel such a need to develop strategies to be effective in gait. The most remarkable change was observed in the anterior position of the trunk (in flexion).
- What brings these two conditions of overload is that both groups have experienced changes in the gait pattern to make this activity more efficiently.
- Despite the changes observed in the results, it is possible that the gait becomes an activity that causes some discomfort. This finding comes from

plantar pressure values and the possible predisposition to the appearance of shear lesions.

- Regardless of the type of overload, it was obvious that individuals adopt a different gait pattern in order to be more efficient performing this activity.

- The strategies developed by these individuals tend to minimize the impact of the forces to which they are subjected during the gait.

Future work

In the future it would be interesting to assess the muscular recruitment pattern during gait of obese individuals and backpackers and relate this variable with the remaining ones, already studied. Relationship of those findings with energy expenditure, work performed and walking efficiency would be of great interest.

It would be interesting to conduct a study that would look to the impact of gait speed of individual's submitted to load.

Another possible future development would be to evaluate the obese individuals after weight loss, and verify how they alter, if they alter, their gait pattern.

An interesting study would be to assess the impact of an orthosis (insole) in the gait of both obese and backpackers.

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Attachments

Attachment 1

THE INFLUENCE OF DIFFERENT SPEEDS ON BACKPACKER'S GAIT KINETICS

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This study analyzed the influence of different speeds on ground reaction force's (GRF), impulses and mean vertical force during gait of people submitted to occasional overload (backpack). A force plate was used to record the GRF data of 60 young adult subjects walking in two different cadences: 69 steps/min (slow gait) and 120 steps/min (fast gait). During the slow gait, the impact and propulsive impulses of vertical GRF, propulsive impulse of anterior-posterior GRF, impulse of medial-lateral GRF and duration of stance phase were larger than during the fast gait; the mean vertical force was the only variable that showed larger values during fast gait. Therefore, slow gait may present a larger possibility of blister development and gait unbalance, while the fast gait, even presenting a small impulse, seems to be more harmful to the musculoskeletal system.

KEY WORDS: backpack, overload, ground reaction force, impulse.

INTRODUCTION: The backpack has been widely used by students, hikers and military as a device to transport load. As a consequence a number of studies have been conducted to identify the biomechanical and physiological impact of this occasional overload on the musculoskeletal system (Birrell et al., 2007; Browning & Kram, 2007; Knapik et al., 1996). Some of the analyzed variables were the impulse or force-time integral of the three components of the ground reaction force (GRF), and mean values of vertical force component (Jordan et al., 2007; Lewek, 2010; Vito et al., 2009). The vertical forces (impulse and mean value) provides information about impact forces, anterior-posterior impulse provides information about impact and blister development and the medial-lateral impulse may be linked to dynamic balance and stability (Birrell, et al., 2007). Changes in walking speed seem to influence the impulse magnitudes. Previous studies found that as the walking speed increases the vertical GRF impulse decreases (Jordan, et al., 2007; Kimberlee et al., 2007; Vito, et al., 2009), while anterior-posterior GRF impulse increases (Chung & Wang, 2010; Vito, et al., 2009). The previous studies, however, have not evaluated the effect of gait speed on GRF with additional loading from carrying a backpack. Therefore the purpose of this study was to analyze the influence of different speeds on GRF' impulses and mean vertical force during gait of people under occasional overload (backpack).

METHODS: The study was approved by the local ethical committee and all participants freely signed an informed consent term, based on Helsinki's declaration, which explained the purpose and the procedures of the study.

Participants: The sample was selected by convenience from university students of sport sciences, and was composed by 60 subjects (30 male and 30 female) with a mean age of 23.0 (± 3.7) years, mean height of 168.0 (± 9.0) cm and mean body mass of 67.8 (± 11.2) kg. All participants were physically active and did not present a body mass index (BMI) above 25, didn't have any traumatic-orthopedic dysfunction nor have difficulties on independent gait.

Instruments: A Bertec force plate (model 4060-15, Bertec Corporation, Columbus, USA), operating at 1000 Hz, was used to measure GRF and a Maelzel metronome (Wittner, Germany) to control the step frequency. Three digital non-coplanar video cameras were used for visual inspection, if necessary.

Experimental Protocol: The participants underwent three phases of testing: preparation, familiarization and testing. In the first phase the procedures to be implemented were explained to the participants and anthropometric data (height and weight) were recorded. A neutral shoe (ballet sneaker) was provided for all participants aiming to minimize the effects of different soles. For each participant the weight to raise their BMI to 30 was calculated; then a backpack was filled with sand and fixed in the central area of each subject's back; the weight placed inside the backpack ranged from 14.1 to 30.1 kg (mean weight 20.3 ± 4.4 kg). This overload was chosen because it is considered to leave the locomotor system more susceptible to injuries (Ko et al., 2010), and the additional upper body mass mimicked obesity, but with the overload in posterior rather than anterior position. In the familiarization process, the participants walked freely over a 6m walkway which had the force plate embedded in the middle; then they trained to walk with two different step frequencies: 69 steps/min (slow gait) and 120 steps/min (fast gait). Participants were asked to try to walk as naturally as possible during these controlled conditions. In this phase the researchers identified the place where the participant should begin the gait to step with his/her right foot in the center of the plate without changing the natural gait pattern. During the test the participants walked three times with a self-selected speed, three times with slow controlled gait, and three times with fast controlled gait. The present study will present data referring to slow and fast gait.

Data analysis: For the acquisition of the force plate data, Acknowledge software (BIOPAC System, California, USA) was used. These data were exported to Matlab® 7.0 (MathWorks, Massachusetts, USA) where a routine was developed to process and calculate the following variables: impact impulse of vertical GRF (Vt_i), propulsive impulse of vertical GRF (Vt_p), braking impulse of anterior-posterior GRF (AP_B), propulsive impulse of anterior-posterior GRF (AP_P), impulse of medial-lateral GRF (ML), mean vertical force (VtF) and duration of stance phase. The events used to calculate impulse variables are illustrated in Figure 1.

Statistical analysis: The mean of the three repetitions performed by each subject was computed and all the statistical procedures were performed with these mean values. The normality of the data was verified using Kolmogorov-Smirnov test and the homogeneity of the variances using Levene's test. Then seven paired t-tests were used to compare the variables between the groups. The results will be presented as mean and standard deviation and the significance level adopted was $\alpha=0.05$. All the statistical procedures were conducted using the software SPSS (v.17; SPSS Inc, Chicago, IL).

RESULTS: The data showed a normal distribution and variances homogeneity. Figure 1 shows that the impulse variables Vt_i , Vt_p , AP_P and ML for the slow gait had higher values compared to the fast gait with statistical significant differences. Despite the AP_B mean values obtained for the slow gait tended to be higher than during fast gait, differences were not statistically significant. Table 1 shows the confidence interval and level of significance of the difference between fast and slow gait obtained by statistical test for all variables. As expected, the duration of stance phase was higher at slow gait (1.091 ± 0.009 s) when compared with fast gait (0.677 ± 0.004 s). Considering the VtF , this variable presents larger magnitude during fast gait (498.9 ± 76.9 N) with statistical significant differences comparatively to slow gait (475.8 ± 71.7 N).

DISCUSSION: The purpose of this study was to compare the two different gait speeds (slow vs fast) in a severe occasional overloading situation (wearing a backpack), comparable to what a subject of BMI=30 may experience. The results suggest that, in this particular situation, the musculoskeletal system need to manage larger impulses during slow than during fast gait, while the VtF is smaller (see Fig. 1 and results). In the following studies (in non-overload conditions), as in the present study, the vertical impulse of GRF decreases with increasing speed during walking (Jordan, et al., 2007; Vito, et al., 2009), but also during running (Jordan et al., 2007). So, it seems that the influence of speed on the behavior of the vertical impulse of GRF is similar during normal and overloaded gait. However, when analyzing only the propulsive impulse (anterior-posterior GRF), Lewek et al. (2010) found,

contrasting with our results, that it increases as gait speed increases in non overloaded conditions. These findings, when compared with the results of the present study indicate a possible difference in the characteristics of a backpacker's gait when compared with normal gait (without overload).

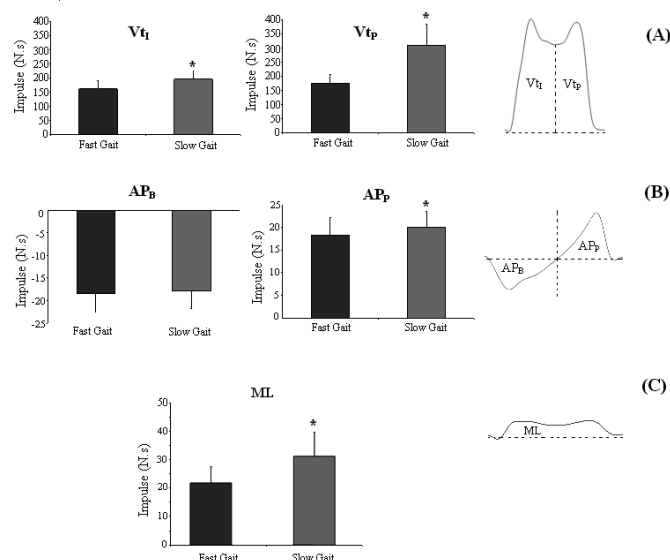


Figure 1: Comparison of impulse variables between fast and slow gait. (A) impulse of vertical GRF; (B) impulse of anterior-posterior GRF and (C) impulse of medial-lateral GRF. V_{t1} - impact impulse of vertical GRF; V_{tp} - propulsive impulse of vertical GRF; AP_B - braking impulse of anterior-posterior GRF; AP_P - propulsive impulse of anterior-posterior GRF; ML - impulse of medial-lateral GRF; * - statistical significant difference $p \leq 0.05$.

Table 1
Confidence interval and level of significance of the difference between fast and slow gait

Variables	95% Confidence Interval of the Difference		Level of significance (p)
	Lower	Upper	
Duration of stance phase	- 0.434	- 0.394	<0.001
Impact impulse of vertical GRF	- 43.286	- 24.899	<0.001
Propulsive impulse of vertical GRF	-149.146	- 118.050	<0.001
Braking impulse of anteroposterior GRF	- 1.638	0.559	0.329
Propulsive impulse of anteroposterior GRF	- 2.437	- 0.762	<0.001
Impulse of mediolateral GRF	- 12.564	- 9.511	<0.001
Mean vertical force	18.937	27.384	<0.001

Impulses depend on the intensity and duration of the application of force. Previous studies on unloaded subjects indicate that when the speed increases peak vertical (Browning & Kram, 2007; Caravaggi et al., 2010; Grabowski, 2010) and anterior-posterior GRF values increase. On the contrary, the duration of stance phase is reduced at higher gait speeds (Caravaggi, et al., 2010; Grabowski, 2010). Consequently, the amount of variation of these two variables will be responsible for the variation of the impulse. The analysis of the present results suggests that the duration of force application affects more the impulse outcome, being responsible for a significant increase on musculoskeletal load (total load, not peaks) during

slow gait. However, analyzing the VtF, it is possible to observe that, during fast gait, there is less time available for musculoskeletal adaptation which makes this situation potentially more aggressive than slow gait considering the viscoelastic properties of the human body tissues. Birrel et al. (2007) found an increase of the GRF' medial-lateral impulse during overloaded gait, and stated that this characteristic may be linked to a decrease in stability of gait dynamic balance. In this sense our results seem to point out that the overloaded slow gait situation may be characterized by a decreased stability when compared with fast gait.

One possible limitation of the present study is the utilization of an acoustical pacer to control different gait conditions (slow and fast). However, the subjective analyzes of video images and the differences observed on the duration of stance phase seem to indicate that this methodological option didn't significantly constrain performance.

CONCLUSION: The results of the present study indicate that the backpacker, walking with a slow speed, is submitted to a higher total mechanical load (impulse) and a lesser mean vertical force when compared to fast gait. Therefore, the backpacker has more time (larger duration of stance phase) to force dissipate during slow gait, what seems to be advantageous for the musculoskeletal system, considering their viscoelastic properties. However, during slow gait the backpacker presented larger magnitudes to propulsive anterior-posterior and medial-lateral impulses when compared to fast gait; and since these variables can provide some information about blister development and balance disturbances, respectively, possibly during slow gait these negative aspects are more pronounced. Therefore, each condition (slow and fast gait) seems to have positive and negative aspects considering these kinetic variables. These gait characteristics can be useful in order to achieve adequate preparation and to promote safety during physical activities and sports performance involving load transportation.

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Attachment 2

ANALYSIS OF THE BACKPACK LOADING EFFECTS ON THE HUMAN GAIT

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KEYWORDS: gait, load, backpack, ground reaction force.

INTRODUCTION: Gait is a simple activity of daily life and one of the main abilities of the human being. Often during leisure, labour and sports activities, loads are carried over (e.g. backpack) during gait. These circumstantial loads can generate instability and increase biomechanical stress over the human tissues and systems, especially on the locomotor, balance and postural regulation systems. According to Wearing (2006), subjects that carry a transitory or intermittent load will be able to find relatively efficient solutions to compensate its effects. These are dependent upon the walking distance and of the load characteristics - size, weight and location relatively to the body (Hsiang, 2002). Thus, these solutions should become a concerning factor (Koh, 2009) and a topic of scientific research, particularly in what concerns the inventory of its biomechanical effects and the possible strategies to be developed in order to minimize its effects.

The aim of the present study was to analyze the effects of an occasional dorso-lombar load during the gait through the use of a backpack.

METHOD: Data was collected from forty healthy subjects (twenty males: mean stature 1.75 ± 0.07 m and mass 72.01 ± 6.75 kg; twenty females: mean stature 1.63 ± 0.06 m and mass 59.45 ± 5.71 kg), students of Sport Sciences with body mass index (BMI) less than 25, aged between 18 and 45 years and without any dysfunction that affect the independent gait. The subjects were informed of the purpose of study and all signed written informed consent.

Gait characterization was accomplished through ground reaction force (GRF) analysis. To collect the GRF data, a BERTEC force plate (model: 4060-15) was used. A devoted amplifier system (BERTEC AM 6300) and a 16 bits analogical-digital conversion unit (BIOPAC) were also used. The sampling rate was established at 1000 Hz.

Each subject was assessed initially in a normal condition (without load) and then loaded (backpack condition). Data were collected regarding three valid rehearsals of each test on the force plate (right foot). Subjects carried on the backpack, fixed at the dorso-lombar region, a static load that allow the subject + backpack to reach the "total BMI" of 30. Each subject walked three times in each condition, at a self-selected velocity, along the experimental walkway (600 cm $\times$ 92 cm $\times$ 15 cm) in which the force plate was engraved.

The results for the three components of the GRF (vertical, anterior-posterior and medial-lateral) were expressed as percentages of the total weight, with and without load. The statistical analysis was conducted with SPSS 16.0 software. Data on independent variables studied were statistically analyzed by measures of central tendency (mean) and dispersion (standard deviation), and compared by paired student t-test (with vs. without load), the significance level adopted was $\alpha=0.05$.

RESULTS: The main results of the study are presented in Table 1. Results include chronometric (temporal) and the dynamometric (GRF) variables. Statistical significant differences ($p < 0.05$) are marked (*). From these we highlight an increase in the stance phase duration and a reduction in the relative magnitude of the first and second peaks of the vertical component in the load condition.

DISCUSSION: During loading, an increase in the two peak values of the vertical GRF component was observed, together with an increase of the stance phase duration. A higher value of the horizontal braking force (anterior-posterior GRF component) was also noted. On the contrary, a reduced maximal value of the latero-medial component was registered. These

results showed that even when the weight of the backpack is included in the calculations of GRF as a percentage of total weight (body + pack), the mean values obtained with and without load traduce a relevant disturbance of the dynamometric profile of the gait pattern. These results conflict with previous results from Tilbury-Davis and Hooper (1999), which evaluated the biomechanical effects of load (20 and 40 kg) in military subjects. Nevertheless, those were trained subjects in this particular task.

Table 1. Mean and standard deviation (Std.) values for the studied chronometric and dynamometric variables obtained for unloaded and loaded situations in both genders

Variables	Normal		Loaded		Confidence Interval		t	Sig.
	Mean	Std.	Mean	Std.	Lower	Upper		
Duration stance phase (s)	0.78*	0.06	0.81*	0.07	-0.055	-0.014	-3.36	0.002
First peak - Vertical Component (N/BW)	1.03*	0.04	0.99*	0.06	0.021	0.057	4.35	0.000
Time (% stance phase)	25.96	3.09	26.68	3.24	-1.674	0.200	-1.59	0.120
Minimum value between Vertical peaks (N/BW)	0.82	0.05	0.82	0.06	-0.016	0.019	0.18	0.859
Time (% stance phase)	46.10	5.95	46.02	4.32	-1.740	1.896	0.09	0.931
Second peak - Vertical Component (N/BW)	1.10*	0.05	1.07*	0.06	0.018	0.052	4.20	0.000
Time (% stance phase)	74.64*	2.46	72.64*	3.40	1.139	2.865	4.69	0.000
Braking Force - anteroposterior component (N/BW)	-0.14*	0.03	-0.15*	0.03	0.003	0.018	2.93	0.006
Time (% stance phase)	18.12	2.66	17.99	1.87	-0.655	0.956	0.38	0.708
Propulsion Force - anteroposterior component (N/BW)	0.19	0.03	0.18	0.03	-0.001	0.014	1.79	0.081
Time (% stance phase)	83.09	1.91	82.99	1.90	-0.473	0.664	0.34	0.736
Peak - mediolateral component (N/BW)	0.10*	0.02	0.09*	0.01	0.002	0.012	2.77	0.009
Time (% stance phase)	46.91	21.91	46.32	18.51	-4.898	6.081	0.22	0.829

* Statistical significance $p < 0.05$

Pierrynowski, Norman and Winter (1981) suggested that gait adjustments occurred when loads of 34kg are carried by subjects whose weight was approximately 72kg (47% body weight). The maximal load used in our research for all the studied subjects was lower than the critical absolute value of 30kg proposed by the referred authors, but sometimes higher in relative terms considering the subject's body weight (57%), which suggest the need of a revision of the boundary proposed by the referred authors. Authors also reported an attenuation of the loading and unloading rates when carrying the higher load of 40kg, suggesting a protection of the biomechanical system. This seems to be in agreement with the reduction of the relative values for the first and second peaks of the vertical GRF component for the load condition obtained in our study, combined with the increased stance duration.

CONCLUSION: The present study showed an adaptation of the subjects to the load condition, with: (i) an increase of the stance phase duration; (ii) a significant reduction of the GRF vertical component peaks, and (iii) an increase of the horizontal braking force.

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Attachment 3

Manuscript Number: JERG-D-11-00234

Title: FORCE AND PRESSURE ANALYSIS DURING OCCASIONAL LOADED GAIT

Article Type: Article

Keywords: backpack; plantar pressure; gait

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Abstract: The aim of this study was to compare the ground reaction forces and plantar pressure parameters between unloaded and occasional loaded gait. The ground reaction forces and plantar pressure of 60 participants were recorded during unloaded and occasional loaded gait (wearing a backpack which raises the participant's body mass index to 30). The results indicate an overall increase of forces and plantar pressure during occasional loaded gait where the absolute values were analyzed ($p < 0.05$), while the normalized values suggested a non-linear relation between backpack mass and plantar pressure increases, where the medial midfoot and toes were more required while the lateral rearfoot was less during loaded gait ($p < 0.05$). Also, during loaded gait the magnitude of impact and propulsive forces decreased and the shear forces increased more than proportion of the load. These data suggest a different pattern of plantar pressure distribution and forces during occasional loaded when compared to unloaded gait.

Cover Letter

We, the undersigned authors of the manuscript entitled “**FORCE AND PRESSURE ANALYSIS DURING OCCASIONAL LOADED GAIT**” submitted to the Applied Ergonomics Journal for publication hereby, attest and affirm that this typescript is an original work that has not been submitted to nor published anywhere else. The authors declare that they do not have any financial or personal relationships with other people or organizations that could have inappropriately influenced this study.

Moreover, the typescript has been read and agreed by all authors.

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Highlights:

1. There is an overall increase on plantar pressure and GRF during loaded gait.
2. Plantar pressure distribution pattern is different between unloaded and loaded gait.
3. In BpG the Midfoot and Toes are most required while the lateral Rearfoot is less.
4. There seems to be a protective behavior during backpacker's gait.

FORCE AND PRESSURE ANALYSIS DURING OCCASIONAL OVERLOAD GAIT

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1. Introduction

The backpack seems to be an appropriate way to carry load by positioning it close to the body's center of gravity while maintaining stability (Chansirinukor et al., 2001); and it has been widely used for different purposes, students fill backpacks with books and stationeries, while hikers and militaries load them with tents and supplies (Al-Khabbaz et al., 2008). Studies analyzing physiological aspects of loaded gait indicate that the energy cost increases progressively with increases of backpack load (Knapik et al., 1996) while biomechanical aspects, by means of kinetic analysis, indicate an increase in magnitude of vertical and anterior-posterior component of ground reaction forces (GFR) (Birrell & Haslam, 2010; Birrell et al., 2007) and increase in peak lumbosacral forces (Goh et al., 1998); by means of kinematic analysis, indicate an increase of range of motion of knee and hip flexion (Attwells et al., 2006; Birrell & Haslam, 2010) and decrease of hip abduction and rotation (Birrell & Haslam, 2010), an increase of forward lean of the trunk and forward position of the head (Attwells et al., 2006; Chansirinukor et al., 2001; Hong & Cheung, 2003), increase of double support time and duration of stance phase (Birrell & Haslam, 2010) and decrease of step length (Birrell & Haslam, 2009); while by means of electromyography analysis the progressively and disproportionally increase of rectus abdominal muscle activity as the load increased (Al-Khabbaz et al., 2008) was also found.

Possibly, the alterations mentioned contribute to a significant association between the backpack weight and occurrence of back pain (Grimmer & Williams, 2000; Skaggs et al., 2006). Johnson et al. (1995) analyzed militaries during road march and it was found that as load increased, fatigue and muscle discomfort intensified, and alertness and feelings of well-being diminished. While Negrini and Carabalona (1999) by means of a cross-sectional research on school children found that 65.7% reported that carrying backpacks causes fatigue and a significant relationship was found between fatigue and back pain. Besides, the higher muscular tensions necessary to sustain these changes have been associated with injury, muscle strain and joint problems (Birrell & Haslam, 2009).

Considering kinetic analyze of backpacker's gait, little is known about where the forces are applied along the plantar surface, because on the previous studies was only used a force plate. For this reason, the inclusion of the insole pressure system in order to kinetic gait assessment seems to contribute to overall understanding of gait kinetics. The combined analysis of the horizontal and vertical component of the GRF and pressure data (distribution of GRF vertical component along the plantar surface) provide more extensive and detailed information about characteristics of the forces acting on the human body. Being possible to develop strategies, such as special insole or gait training, to minimize the impact that this occasional overload has

on the locomotor system. Therefore the aim of the present study was to compare the GRF and plantar pressure parameters between unloaded and occasional loaded gait.

2. Methods

2.1. Participants

The sample was selected by convenience from university students of sport science and all of them were physically active and presented a body mass index (BMI) lower 25; besides, if they showed any traumatic-orthopedic dysfunction or some difficulties on independent gait would be excluded. Therefore 60 subjects (30 male and 30 female) with a 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 were enrolled in the study. This research was approved by a local ethical committee and all participants freely signed an informed consent term, based on Helsinki's declaration, which explained the purpose and the procedures of the study.

2.2. Apparatus

A Bertec force plate model 4060-15, operating at 1000 Hz, and an amplifier signals system model AM 6300 (Bertec Corporation, Columbus, USA), a Biopac analog-digital converter (BIOPAC System, California, USA) and a F-Scan insole pressure system (TekScan, South Boston, USA) operating at 300 Hz with about 960 pressure cells and a 0.18 mm thick insole sensor were used to kinetic gait characterization. Three digital cameras were used for visual inspection, if necessary.

2.3. Tasks and procedures

The participants underwent three phases: preparation, familiarization and test. In the first phase it was explained to participants the procedures which would be performed and anthropometric data (weight and height) were recorded. For each participant was calculated the weight to raise their BMI to 30, then a backpack was filled with sand and fixed at the central area of each subject's back; the load placed inside the backpack ranged from 14.1 to 30.1 kg (mean load 20.3 ± 4.4 kg). This overload was chosen because it is considered to leave the locomotor system more susceptible to injuries (Ko et al., 2010). A cuff unit measuring 98 x 64 x 29 mm with Velcro strap up was attached on the lateral malleolus region of both legs of each participant and a 9.25 mm cable linked the cuff to the VersaTek hub (F-Scan system) which was beside the walkway and connected to a computer; the cable did not cause any restriction for the gait. A pair of thin socks and, aiming to minimize the effects of different soles, a neutral shoe (ballet sneaker) with sensor insoles was provided for all participants. During the familiarization the participants walked freely (without backpack) over a 6m walkway where the force plate was embedded at the middle; in this moment the researcher identified the site where the participant should begin the gait to tramp with all surface of his right foot over the plate without altering their gait pattern. In the last phase the participants performed three valid tests without backpack

(unload condition which was called control group – CG) and three valid testes with backpack (loaded condition which was called backpacker's group – BpG), where they walked with a self-selected speed looking forward and performed, at least, two steps before and after reaching the plate. The tests were considered valid when the subjects reached the plate with all the foot over it, and by means of visual inspection, did not alter their gait pattern.

2.4. Data Analysis

For the acquisition of force plate and insole pressure system data were used, respectively, the Acknowledge (BIOPAC System, California, USA) software and the F-Scan Research 6.33 (TekScan, South Boston, USA) software. The data from the force plate (three GRF components) and the insole pressure system (values of each sensor in each frame) were exported to Matlab 7.0 (MathWorks, Massachusetts, USA) software and a program was developed to the processing and calculation of the analyzed variables.

All force and pressure variables were showed 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.

Considering force plate data, dependent variables were calculated to absolute (Abs) and normalized ($Norm$) values and time ($Time$), respectively, for the following events: impact (first peak ($PkVt_{I_Abs}$, $PkVt_{I_Norm}$ and $PkVt_{I_Time}$), minimum between the peaks (Vt_{Min_Abs} , Vt_{Min_Norm} and Vt_{Min_Time}) and the thrust maximum (second peak) ($TMVt_{Abs}$, $TMVt_{Norm}$ and $TMVt_{Time}$) of the GRF vertical component; braking (negative) peak ($PkAP_{B_Abs}$, $PkAP_{B_Norm}$ and $PkAP_{B_Time}$) and propulsive (positive) peak ($PkAP_{P_Abs}$, $PkAP_{P_Norm}$ and $PkAP_{P_Time}$) of GRF anterior-posterior component; and duration of stance phase were calculated.

Considering insole pressure system data, firstly the program divided the foot into 10 regions as proposed and adapted on previous studies (Cavanagh & Ulbrecht, 1994; Gurney et al., 2008). Where the boundary between the rearfoot (RF) and midfoot (MF) was located 73% of the foot length (from toes to heel direction), being the RF divided into three equal parts (33% each); the boundary between MF and forefoot (FF) was located 45% along this length, being the MF divided into two equal parts (50% each); the FF was divided into three regions being 30% medial (first metatarsal region), 25% central (second metatarsal region) and 45% lateral (lateral metatarsals region); and the other two regions were the hallux (Hlx) and lesser toes (Toes) (2nd, 3rd, 4th and 5th toes). Therefore, dependent variables were calculated to absolute and normalized values for the sensor peak (Pk) and time of sensor peak occurrence for these 10 foot regions, respectively, for the 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}); the 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 too. The program divided automated the plantar regions, however all divisions were checked by two trained researchers and, if necessary (eventually), corrected manually.

Since the insole pressure system presents good information about relative distribution of plantar forces while their absolute values have been questioned (Nicolopoulos et al., 2000; Rosenbaum & Becker, 1997; Woodburn & Helliwell, 1996) and the force plate is considered the most accurate dynamic measurements of force (Cobb & Claremont, 1995); the force plate was used to calibrate (post-test) the insole pressure system 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 repetitions of each subject was computed and all the statistical procedures were performed with these mean values. The normality of the data was verified using Kolmogorov-Smirnov test and the homogeneity of the variances using Levene's test; of 96 sets of value calculated (48 for each group), 7 of them did not present normal distribution (PkHlx_{Abs} in both groups, PkRF_{lat_Abs}, PkRF_{ct_Abs} and PkRF_{med_Abs} in CG, and PkRF_{med_Abs} and PkToes_{Norm} in BpG) so the natural logarithmic transformation was performed and these new variables presented normal distribution, being it used to 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 $\alpha = 0.05$. The results will be presented as mean, standard deviation and confidence interval of the variables. The statistical procedures were made using SPSS (v.17; SPSS Inc, Chicago, IL, USA) software.

3. Results

The variables PkFF_{ct_Abs}, PkRF_{ct_Abs}, PkVt_{I_Abs}, and duration of stance phase showed ICC of 0.98 (CI_{95%} 0.97 – 0.99), 0.97 (CI_{95%} 0.95 – 0.98), 0.86 (CI_{95%} 0.78 – 0.91), 0.94 (CI_{95%} 0.90 – 0.96), respectively; indicating excellent data repeatability.

By looking to Table 1 we can see that the duration of the stance phase and the initial double limb stance were longer during BpG gait when compared to CG, while the final double limb stance did not show statistical differences.

---Table 1 ---

In the BpG 9 of 10 plantar regions showed larger absolute pressure values with $p < 0.05$ when compared to CG, only on the lateral MF the differences did not have statistical

significance (Figure 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; and in CG 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 at PkToes and MF_{Med} while lower magnitudes at PkFF_{Lat} when compared to CG (Figure 1A).

In all GRF events analyzed the BpG presented larger absolute force values with $p < 0.05$ when compared to CG (Figure 1B). And when the normalized force values were analyzed, the PkVt_{I_Norm} and PkAP_{B_Norm} also showed larger values in BpG when at TMVt_{Norm} the differences were observed in the opposite direction when compared to CG. The Vt_{Min_Norm} and the PkAP_{P_Norm} did not present statistical differences between groups (Figure 1B). Considering time variables (peak time), the PkMF_{Med_Time} occurred earlier while the TMVt_{Time} occurred later in the CG when compared to BpG, the other time variables did not present statistical differences (Figure 1B).

--- Figure 1 ---

Considering the comparison between groups (Table 2), the larger absolute force differences were found in the following variables, respectively, at TMVt, PkVt_I and Vt_{Min}; where the BpG presented the higher values. And regarding the normalized force differences, the variables that presented larger values were, respectively, at Vt_{Min} and TMVt where the BpG presented lower and at PkAP_B where the BpG presented larger magnitudes when compared to CG (Table 2). Considering pressure data, larger absolute differences occurred in the medial FF, followed by the medial and central RF region; while the larger normalized differences occurred in Toes, followed by medial FF and Halux region; in all of these pressure differences the BpG showed the larger values (see Table 2).

--- Table 2 ---

4. DISCUSSION

The present study investigated the influence of occasional load in the force and pressure parameters during gait. Other studies, corroborating with our data, have already reported that during occasional loaded gait (BpG) there was an overall increase in GRF parameters (Birrell et al., 2007; Chow et al., 2005; Harman et al., 2000). On the other hand, the combined analysis of GRF parameters normalized by the total weight (body mass plus backpack mass) is scarce in the literature while the plantar pressure distribution during occasional overload gait, as far as we know, was not reported yet. Considering kinetic analysis, only the absolute values of the GRF parameters provide a limited understanding of the plantar foot forces, therefore the present study carried out an integrated analysis approach, which allowed to know not only the load supported by the human been (absolute values) but also understand the gait pattern (normalized values)

and, simultaneously, the analysis of the behavior of loads in specific plantar regions by means of insole pressure system, enabling us to acquire detailed information about change magnitudes of the plantar force and alterations of the gait characteristics promoted by carrying a backpack filled with a potential harmful load.

4.1 Rearfoot Region

Our data showed an increase of the impact forces (absolute values) in BpG, results similar to its have already been showed before (Birrell & Haslam, 2010; Birrell et al., 2007; Harman et al., 2000; Tilbury-Davis & Hooper, 1999). Birrel et al. (2007) found a linear increase between vertical force with the load applied inside the backpack suggesting that the increase in force is predominantly due to the static effect of the load rather than changes in acceleration of the system. However, the data of the present study (normalized values) indicated a non linear relation between vertical force (PkV_{t_i} and TMV_t) and backpack load, which suggest a gait pattern adaptation in order to minimize the excess loading in BpG; Tilbury-Davis and Hooper (1999) corroborate with this non linear relationship, the authors observed a protective response of the locomotor system in order to mitigate a potential injury during military gait carrying backpacks weighting 20 and 40 kg.

On the other hand the $PkAP_B$ was larger (absolute and normalized), indicating that the breaking forces are potentiated (increased more than backpack mass) during occasional overload gait. Other studies corroborate with the absolute increases of the breaking force (Birrell & Haslam, 2010), while its increase even after normalized by the total weight, as far as we know, had not been reported. This anterior-posterior force helps slowing the body down during the initial part of the gait cycle (Birrell & Haslam, 2010) and, its increase, seems to be a relationship with the 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 occurrence; although, the authors did not assess plantar pressure as in the present study; therefore, our data support this suggestion, where during overload gait there were pressure increase in all RF regions (medial, central and lateral). So, the knowledge of this behavior ($PkAP_B$ and RF pressure increase) may contribute to understand the mechanism behind the development of this injury (blister), which is the most common related to load carriage (Knapik et al., 1997).

4.2 Midfoot Region

When we analyze the MF, seems that the medial region is very used to download during gait in the BpG, because even analyzing normalized data, larger values were found when compared to CG; Filippin et al. (2007) analyzing permanent loaded gait (obese children) found

different results, where similar pressure peaks and larger contact area in medial MF were evidenced when compared to non-obese children, the authors stated that this results probably occurred due to the well-known changes in the feet of obese people, where the plantar arch becomes flat after excessive and repetitive loads; our data showed that this region (medial MF) is overloaded in BpG, being possible that this alteration be an acute adaptation promoted by occasional overload (backpack) in the gait; and, when often repeated as in permanent loaded gait (obese people), may be one of the factors that contributes to the development of the plantar arch flattening. While we analyzed the lateral MF, it was noted that during loaded gait the values were similar than those found in CG suggesting that during occasional loaded gait the medial MF is more required while the lateral MF seems to be protected. Considering V_{tMin} the results were as expected, larger magnitudes as absolute data and similar magnitudes as the normalized data, which indicate that there is no pattern alteration in this variable during occasional loaded gait.

4.3. Forefoot Region

Considering the pressures and forces acting at the FF, as expected all variables (TMV_{tAbs} , $PkAP_{P_Abs}$, $PkHlx_{Abs}$, $PkToes_{Abs}$, $PkFF_{Med_Abs}$, $PkFF_{Ct_Abs}$ and $PkFF_{Lat_Abs}$) showed larger magnitudes in BpG when compared to CG; the medial FF was the region that presented the highest pressure increases when 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), indicating a higher recruitment of the medial region to support the overpressure during gait. Rather, when the data were normalized by the total weight we expected that there were no differences between groups; however, in the $PkToes$ the values continued larger in BpG suggesting that during occasional loaded gait the toes region was more required than in the unloaded gait. Differences also were found in TMV_{tNorm} where the BpG showed lesser normalized values; possibly this occurred because the backpack promotes an increase of the forward lean in response to center of mass posteriorization during gait, thus the forces needed to advance during mid-stance to toe-off phase is reduce, by means of reducing the passive momentum of the body (Birrell & Haslam, 2010).

4.4. Time Variables

In this study during BpG gait there was an increase in duration of stance phase and initial double stance when compared to CG; Singh and Koh (2009) , Hong and Brueggmann (2000) and Chow et al. (2005) found that in primary school students carrying a backpack with a percentage between 10% and 20% of the body mass there was a larger initial double stance when compared a unloaded gait, even with the participants of the present study being older and carrying a backpack heavier (32.2% of the body mass, $CI_{95\%}$ 29.5 to 34.8), our data

corroborates with the previous studies mentioned. One possible explanation for this behavior is that walking with a backpack raises the combined center of mass of the backpack and the body posterior and superiorly inducing postural imbalance for static and dynamic conditions (Hong & Brueggemann, 2000; Singh & Koh, 2009), in response to it, a higher amount of double stance time may be an attempt to minimize the duration of unsteady single-limb stance (Hong & Brueggemann, 2000) and brings down the combined center of mass providing a counter effect to stabilize gait for loaded conditions (Singh & Koh, 2009). Differences also were found at $PkMF_{Med_Time}$ and $TMV_{t_{Time}}$ which occurred, respectively, later and earlier in BpG when compared to CG; possibly the increase of the initial double stance may promote this delay in $PkMF_{Med}$ download while the posterior shifting (Birrell & Haslam, 2010) of the center of mass may be responsible by this anticipation at the $TMV_{t_{Time}}$.

Some possible limitation in this study should be considered: firstly, the backpack load used was not the same for all participants; we could have used, to normalize the load, the percentage of the body mass or a fixed load, however, since the locomotor system of people with $BMI \geq 30$ is considered more susceptible to injuries (Ko et al., 2010), we preferred to use the $BMI = 30$ as overload normalization and, in order to promote a stressful load, it seems to us that it was a good way of do it. Secondly, the adopted gait speed in the present study was the one which the subjects felt more comfortable (self-selected) and such behavior can influence the characteristics of the force, on the other hand self-selected speed prevents disturbances in the gait pattern and ensure a normal walking (Pieter et al., 2009); moreover, the statistical tests used were paired, being the speed intra-individual between conditions probably very similar, thus we believe that it was the best choice. Finally, the pressure analysis only considered the vertical forces, therefore we do not know the behavior of the regional shear forces, however, as far as we know, there are very restricted devices that are able to perform this kind of analyze; alternatively, we have analyzed the anterior-posterior GRF, allowing important evidence about shear forces.

5. Conclusions

In conclusion, was observed an overall increase at the plantar pressure and GRF parameters and alterations in gait pattern during occasional loaded gait (BpG) when compared to the CG. Being the medial MF and Toes the most required during occasional loaded gait while the lateral RF less (non linear relationship between pressure and backpack mass), and considering the other regions, a linear increase occurred. Also, in order to diminish the magnitude of impact and propulsive forces was evidenced one protective behavior in the BpG; on the other hand, the shear forces have increased more than the proportion of the load, which may mean in higher susceptibility to develop blister in BpG. Therefore, seems necessary to specify adaptations in training or in material (shoe, insole, socks, etc.) of people under occasional overload (students,

hikers, military, etc.) to improve the capacity to handle the overload during gait and prevent injuries.

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Abbreviations

GRF: ground reaction forces

BMI: body mass index

CG: control group

BpG: backpack's group

Abs: absolute

Norm: normalized

Time: time of the event

Pk: peak

V_t: impact peak

V_{tMin}: minimum between the peaks

TMVt: thrust maximum

PkAP_B: braking (negative) peak

PkAP_P: propulsive (positive) peak

RF: rearfoot

MF: midfoot

FF: forefoot

Hlx: hallux

Toes: 2nd, 3rd, 4th and 5th toes

Med: medial

Ct: central

Lat: lateral

ICC: intra-class correlation coefficient

CI: confidence interval

SD: standard deviation

p: significant level

Titles and Legends

Figure 1A. Peak's pressure (absolute and normalized values) of each foot's region and respective time. B. Force (absolute and normalized values) and respective time of the mainly events of ground reaction force (GRF). PkV_{t1} - 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's group equal body weight plus backpack weight); Y axis presents time of the events to control group (first value) and backpacker's group (second value). * - statistical difference with $p < 0.05$.

Table 1

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

Table 2.

Mean, standard deviation (SD), confidence interval and significant level (p) of the differences between CG and BpG for all force and pressure variables.

Legend

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.

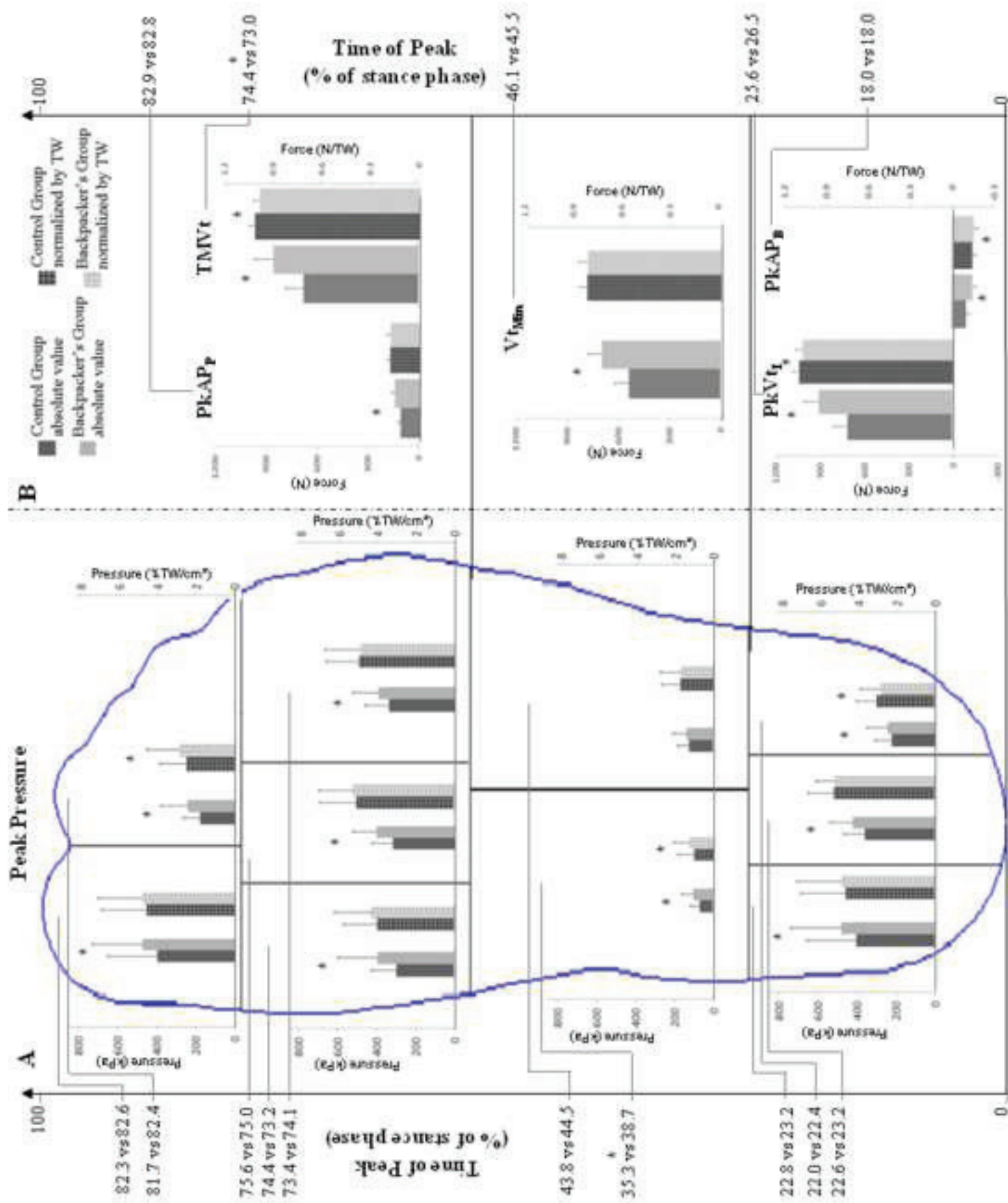


Table 1. Mean, standard deviation (SD) and significant level (p) of the stance time variables.

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

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

Variables	ABSOLUTE DATA					NORMALIZED DATA				
	Mean		Confidence Interval			Mean		Confidence Interval		
<i>Force</i>	(N)	SD	Lower	Upper	<i>p</i>	(N/TW)	SD	Lower	Upper	<i>p</i>
PkV _{tI}	-177.262	74.480	-196.846	-157.679	< 0.001	0.032	0.048	0.018	0.045	< 0.001
V _{tMin}	-159.510	56.006	-174.105	-144.915	< 0.001	0.003	0.049	-0.009	0.016	0.586
TMV _t	-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
<i>Pressure</i>	(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.