



# CATÓLICA

UNIVERSIDADE CATÓLICA PORTUGUESA | PORTO  
Escola Superior de Biotecnologia

INFLUENCE OF WALKING SPEED IN BACKPACKER'S GAIT:  
GROUND REACTION FORCES AND PLANTAR PRESSURE ANALYSIS

by

Maria Cristina Pinto Leite Braamcamp Figueiredo

March 2011





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INFLUENCE OF WALKING SPEED IN BACKPACKER'S GAIT:

GROUND REACTION FORCES AND PLANTAR PRESSURE ANALYSIS

Thesis presented to *Escola Superior de Biotecnologia* of the *Universidade Católica Portuguesa*  
to fulfill the requirements of Master of Science degree in Biomedical Engineering

by

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## Resumo

O modo como nos deslocamos influencia os parâmetros biomecânicos da marcha, alterando-os, podendo vir a originar lesões a curto ou longo prazo. Com este trabalho pretendeu-se fazer, em primeiro lugar, uma revisão sistemática da literatura acerca do que consiste a influência da velocidade nos parâmetros biomecânicos da marcha e, depois, estudar o efeito que a velocidade tem nas forças de reacção ao solo e na pressão plantar durante a marcha quando se transporta, ou não, uma carga. Assim, um dos objectivos deste estudo foi sistematizar o conhecimento vertido na literatura do século XXI sobre o efeito do aumento da velocidade na biomecânica da marcha. Foi feita uma pesquisa em três bases de dados (PubMed, Science Direct e Scopus) entre 2001 e 2010 com os termos: (gait OR walking OR walk) AND (velocity OR speed) AND (ground reaction force OR kinetics OR kinematics OR biomechanical OR biomechanics OR plantar pressure OR mathematical model) AND (comparison OR compare OR change OR relation OR influence). Um total de 71 artigos foram seleccionados relativos a variáveis de pressão plantar, cinética, cinemática e electromiografia. Os resultados mostram que existe um grande consenso em relação às seguintes variáveis: (i) duração da fase de apoio; (ii) frequência de passo e passada; (iii) comprimento do passo e passada; (iv) duração da fase de duplo apoio; (v) duração do ciclo da marcha; (vi) pico de pressão; (vii) força máxima; (viii) picos e mínimo intermédio da força de reacção ao solo (FRS) vertical; (ix) tempo para os picos e o mínimo intermédio da FRS vertical; (x) impulso vertical; (xi) picos da FRS anterior-posterior; (xii) impulso anterior-posterior; (xiii) pico dos momentos; (xiv) pico das potências; (xv) trabalho mecânico; (xvi) amplitudes do centro de massa; (xvii) actividade muscular. Contudo, o principal objectivo deste estudo foi investigar o efeito sobre os parâmetros dinamométricos da marcha, traduzidos pelas forças de reacção do solo e pela distribuição plantar de pressão, do transporte de uma carga ocasional a diferentes velocidades. Sessenta indivíduos com uma idade média de  $23.0 \pm 3.7$  anos, altura média de  $168.0 \pm 0.1$  cm e uma massa corporal média de  $67.8 \pm 11.2$  kg foram inscritos neste estudo. Os participantes caminharam a uma velocidade lenta (68 passos/s) e rápida (112 passos/s) com e sem uma mochila carregada com uma carga que aumenta, em cada indivíduo, o "índice de massa corporal total" para 30. Os parâmetros de pressão plantar foram medidos utilizando o sistema de palmilhas de pressão F-Scan e as forças de reacção ao solo foram recolhidas utilizando uma plataforma de forças Bertec. Os resultados mostram que há um aumento de ambos os picos da FRS vertical e de ambos os picos da FRS anterior-posterior, enquanto o mínimo intermédio da FRS vertical diminuiu, em ambas as condições de carga. O *hallux*, os outros dedos, o antepé lateral e central e o retropé medial e central foram as regiões do pé que apresentaram um aumento de pressão quando a velocidade aumentou, em ambas as condições de carga. A duração da fase de apoio diminuiu à medida que a velocidade aumentou nas duas condições de carga. O padrão de marcha parece ser influenciado pela sobrecarga ocasional, nos parâmetros de pressão plantar e nalguns parâmetros temporais da marcha.



## Abstract

The way we move can influence gait biomechanical parameters, and may, eventually, lead to damage and injury in short or long term. With this study we intended to, in first place, conduct a literature systematic review on the influence of speed in gait biomechanical parameters, and then investigate the effect of speed and backpack carrying on ground reaction force and plantar pressure parameters during gait. The first aim of this study was to systematically review the literature of the XXI century on the effect of increased speed on gait biomechanics. Three data base (PubMed, Science Direct and Scopus) were searched from 2001 to 2010 using the terms: (gait OR walking OR walk) AND (velocity OR speed) AND (ground reaction force OR kinetics OR kinematics OR biomechanical OR biomechanics OR plantar pressure OR mathematical model) AND (comparison OR compare OR change OR relation OR influence). A total of 71 papers were selected, dealing with analysis based on plantar pressure, kinetical, kinematical and electromyography variables. Results showed that there is a large consensus regarding the following biomechanical effects of gait speed increase: (i) time duration of stance; (ii) stride and step frequency; (iii) stride and step length; (iv) time duration of double support phase; (v) time duration of gait cycle; (vi) peak pressure; (vii) maximum force; (viii) vertical ground reaction force (GRF) peaks and intermediate minimum; (ix) time to vertical GRF peaks and intermediate minimum; (x) vertical impulse; (xi) anterior-posterior GRF peaks; (xii) anterior-posterior impulse; (xiii) peak moments; (xiv) peak powers; (xv) mechanical work; (xvi) centre of mass amplitudes; (xvii) muscle activity. However, the main aim of this study was to investigate the influence of the speed in ground reaction force and plantar pressure parameters during occasional overload gait, compared with the unloaded condition. Sixty participants with a mean age of  $23.0 \pm 3.7$  years, mean height of  $168.0 \pm 0.1$  cm and mean body mass of  $67.8 \pm 11.2$  kg were enrolled in this study. The participants walked on a walkway at a slow (68 steps/s) and a fast (112 steps/s) speed with and without wearing a backpack which raise their "total body mass index" to 30. Plantar pressure parameters were measured with an F-Scan insole pressure system and ground reaction forces were collected using a Bertec force plate. Results showed that there is an increase of both vertical and both anterior-posterior GRF peaks, while the intermediate minimum of the vertical GRF decreased during both conditions (with and without backpack). *Hallux*, lesser toes, lateral and central forefoot and medial and central rearfoot were the foot regions that presented an increase of peak pressure while speed increased, for both conditions. Stance phase duration decreases as speed increases, for both load conditions. Gait pattern seems to be influenced by occasional overload in plantar pressure parameters, double support and temporal gait events, like heel strike and toe off.



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## List of abbreviations

AP	anterior-posterior
BMI	body mass index
BpG	backpacker's group
CG	control group
EMG	electromyography
FF	forefoot
RFS	força de reacção ao solo
GRF	ground reaction force
HI	hallux
IMC	índice de massa corporal
MF	midfoot
PkAP <sub>B_Abs</sub>	anterior-posterior GRF breaking peak absolute value
PkAP <sub>B_Norm</sub>	anterior-posterior GRF breaking peak normalized value
PkAP <sub>B_Time</sub>	time to anterior-posterior GRF breaking peak
PkAP <sub>P_Abs</sub>	anterior-posterior GRF propulsive peak absolute value
PkAP <sub>P_Norm</sub>	anterior-posterior GRF propulsive peak normalized value
PkAP <sub>P_Time</sub>	time to anterior-posterior GRF propulsive peak
PkFF <sub>Ct_Abs</sub>	central forefoot maximum pressure peak absolute value
PkFF <sub>Ct_Norm</sub>	central forefoot maximum pressure peak normalized value
PkFF <sub>Ct_Time</sub>	time to central forefoot maximum pressure peak
PkFF <sub>Lat_Abs</sub>	lateral forefoot maximum pressure peak absolute value
PkFF <sub>Lat_Norm</sub>	lateral forefoot maximum pressure peak normalized value
PkFF <sub>Lat_Time</sub>	time to lateral forefoot maximum pressure peak
PkFF <sub>Med_Abs</sub>	medial forefoot maximum pressure peak absolute value
PkFF <sub>Med_Norm</sub>	medial forefoot maximum pressure peak normalized value
PkFF <sub>Med_Time</sub>	time to medial forefoot maximum pressure peak
PkHlx <sub>Abs</sub>	hallux maximum pressure peak absolute value
PkHlx <sub>Norm</sub>	hallux maximum pressure peak normalized value
PkHlx <sub>Time</sub>	time to hallux maximum pressure peak
PkMF <sub>Lat_Abs</sub>	lateral midfoot maximum pressure peak absolute value
PkMF <sub>Lat_Norm</sub>	lateral midfoot maximum pressure peak normalized value
PkMF <sub>Lat_Time</sub>	time to lateral midfoot maximum pressure peak
PkMF <sub>Med_Abs</sub>	medial midfoot maximum pressure peak absolute value
PkMF <sub>Med_Norm</sub>	medial midfoot maximum pressure peak normalized value
PkMF <sub>Med_Time</sub>	time to medial midfoot maximum pressure peak

PkRF <sub>Ct_Abs</sub>	central rearfoot maximum pressure peak absolute value
PkRF <sub>Ct_Norm</sub>	central rearfoot maximum pressure peak normalized value
PkRF <sub>Ct_Time</sub>	time to central rearfoot maximum pressure peak
PkRF <sub>Lat_Abs</sub>	lateral rearfoot maximum pressure peak absolute value
PkRF <sub>Lat_Norm</sub>	lateral rearfoot maximum pressure peak normalized value
PkRF <sub>Lat_Time</sub>	time to lateral rearfoot maximum pressure peak
PkRF <sub>Med_Abs</sub>	medial rearfoot maximum pressure peak absolute value
PkRF <sub>Med_Norm</sub>	medial rearfoot maximum pressure peak normalized value
PkRF <sub>Med_Time</sub>	time to medial rearfoot maximum pressure peak
PkToes <sub>Abs</sub>	lesser toes maximum pressure peak absolute value
PkToes <sub>Norm</sub>	lesser toes maximum pressure peak normalized value
PkToes <sub>Time</sub>	time to lesser toes maximum pressure peak
PkVt <sub>F_Abs</sub>	vertical GRF first peak absolute value
PkVt <sub>F_Norm</sub>	vertical GRF first peak normalized value
PkVt <sub>F_Time</sub>	time to vertical GRF first peak
PkVt <sub>S_Abs</sub>	vertical GRF second peak absolute value
PkVt <sub>S_Norm</sub>	vertical GRF second peak normalized value
PkVt <sub>S_Time</sub>	time to vertical GRF second peak
RF	rearfoot
SP	stance phase
Toes	lesser toes
Vt	vertical
Vt <sub>Min_Abs</sub>	vertical GRF intermediate minimum absolute value
Vt <sub>Min_Norm</sub>	vertical GRF intermediate minimum normalized value
Vt <sub>Min_Time</sub>	time to vertical GRF intermediate minimum

# Introduction



Because gait is the most efficient and natural human locomotion solution, studies centered in its characteristics seem to be growing in number over the last centuries. Gait is being studied since the XVIII century. As a consequence, it is already well known how the gait cycle is developed. However, the biomechanical effects of overloaded gait situations seem to be not so deeply understood.

The gait cycle begins when heel touches the ground, and ends when the same heel touches the ground again. Gait is also characterized by having, always, a support phase, i.e., a foot touching the ground. Gait cycle has a stance phase and a swing phase. Stance phase corresponds to 60% of gait cycle while swing phase represents the others 40%. During stance phase, there is an initial phase of double support (10%), following by a single support phase (40%) and ends with a double support phase (10%), again (Vaughan et al., 1999).

Lately, studies about gait concerned to understand how gait is affected by external factors – like speed, load carriage, etc.

It is well known that the way we move can influence gait biomechanical parameters, such as kinematics, kinetics, muscle activity as measured by electromyography (EMG), and spatio-temporal parameters (Michael et al., 2008).

Changes in gait speed bring new biomechanical adaptations that can be different for also different load conditions, determining specific understandings about the most suitable solution for load transport.

In fact, it is also known that carrying load has an effect on gait parameters, mainly because load carriage alters the inertial characteristics of the body-load system in much the same way as in a passive model (Hsiang and Chang, 2002). Studies on the effects of load carriage on gait have shown changes in stride parameters that include increased stride frequency, double support time, and decreased stride length (LaFiandra et al., 2002). Increasing load it is also expected that ground reaction forces increase (LaFiandra et al., 2002) . Nevertheless, the knowledge about the combined effect of gait speed and load seem to remain obscure.

So, this study will discuss, primarily, the influence of ambulatory speed in gait biomechanical parameters and, secondly, the influence of speed during normal gait (unload condition) and backpacker's gait (occasional overload condition) in GRF and plantar pressure parameters during gait.

This thesis will consist in a systematic review paper:

**The influence of ambulatory speed in gait biomechanical parameters**

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(To be submitted to the Journal of Human Kinetics, ISI indexed, Impact Factor = 0.3)

and an original paper:

**Influence of walking speed in backpacker's gait on ground reaction forces and plantar pressure parameters**

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# **Chapter 1 – Systematic review**

## ***The influence of ambulatory speed in gait biomechanical parameters***

KEY WORDS: Biomechanics, Gait, Speed, Systematic literature review



## **1. Introduction**

Gait studies seem to be growing in number through the last years of biomechanical research. This may be explained by the increased interest in the definition of gait normality and variability, allowing to: (i) characterize ontogenetic evolution and involution of gait; (ii) define pathological or abnormal situations; (iii) characterize the acute impact of different interventions (surgical, physiotherapeutic, and physical training), or (iv) characterize the impact of different performance conditions (fatigue, load, group performance, orthoses and other interfaces – like shoes, insoles, floors, etc.).

To fulfill most of the previously referred aims, we need to essaying standardizing the performance context, namely in what concerns: (i) gait speed and (ii) ground inclination – leveled, uphill, and downhill. Among these factors, gait speed seems to be the more decisive factor to be controlled, once it should be considered in any inclination context. Moreover, we are constantly experiencing speed changes during locomotion, both because the production and application of forces (propulsive and resistive) is not constant, and because the mechanisms of neuro-mechanical control are changing in time.

It is well known that walking speed influences the fundamental elements of gait — joint rotations (kinematics), ground reaction forces (GRF), net internal joint moments and joint power (kinetics), muscle activity as measured by electromyography (EMG), and spatio-temporal parameters such as stride length, and cadence (Michael et al., 2008). Furthermore, it is generally accepted that gait parameters follow a consistent pattern of change in response to varying gait speed (Lelas et al., 2003). However, some mechanisms, such as the one of transmitting increased impulse to the ground as walking speed increases, seems to be not yet fully understood (Todd et al., 2008).

With this study we are aiming to expose, in a systematic way considering what has been written about this subject, the state of the art in the topic of how speed affects biomechanical relevant gait parameters. We secondarily aimed to identify the variables that had been already studied and the consistency of the associated findings, depicting any conceptual conflict in the results obtained in the topic.

## **2. Methodology**

A systematic research of studies that took in account different gait speeds was conducted in digital databases, based on inclusion and exclusion criteria previously defined. Due to its relevance and coverage, the following databases, time course of the search and domains were selected:

- PubMed (in the last 10 years, i.e. 2001 to 2010, on the title or abstract)
- Science Direct (since 2001, i.e. 2001 to 2010, on the title, abstract or key-words)
- Scopus (since 2001, i.e. 2001 to 2010, on the abstract)

## **2.1. Research terms**

On the three databases chosen, search was conducted using the following terms: (gait *OR* walking *OR* walk) *AND* (velocity *OR* speed) *AND* (ground reaction force *OR* kinetics *OR* kinematics *OR* biomechanical *OR* biomechanics *OR* plantar pressure *OR* mathematical model) *AND* (comparison *OR* compare *OR* change *OR* relation *OR* influence).

## **2.2. Inclusion criteria**

All the studies that reported human gait speed related with some biomechanical parameter, written in English, were included in this study. We only considered the studies in which the target was the normal gait analysis (without any gait dysfunction or pathology).

## **2.3. Exclusion criteria**

Those studies where subjects with gait disorders were studied or those that studied animals instead of humans, were excluded from this study. There were also excluded all the studies of others decades and those not written in English.

## **2.4. Data analysis**

For all the selected studies, a brief characterization was done – title, authors, methods, and variables –, and a synthesis of results and conclusions. A meta-analysis of the selected studies was also conducted. The categories of the biomechanical approach and the date of publication of the papers were taken into consideration for this purpose.

## **3. Results**

The database search that was conducted for the first decade of the XXI century allowed to select sixty nine studies ( $n = 69$ ), from which six were excluded, because they did not satisfy the inclusion criteria. The remaining studies ( $N = 63$ ) were ordered by the category of biomechanical parameters studied – plantar pressure, kinetics, kinematics and EMG.

In Figure 1.1, it can be seen how papers are distributed by the four categories of biomechanical parameters analyzed – plantar pressure, kinetic, kinematic and EMG. In Figure 1.2 the distribution of the studied papers across the years is shown. It can be seen that the sum of papers present in the four categories (plantar pressure, kinetic, kinematic and EMG) is eighty

five (85) papers, and this happens because there are some papers that use two or more protocols. The most part of them combine kinetic with kinematic protocols.

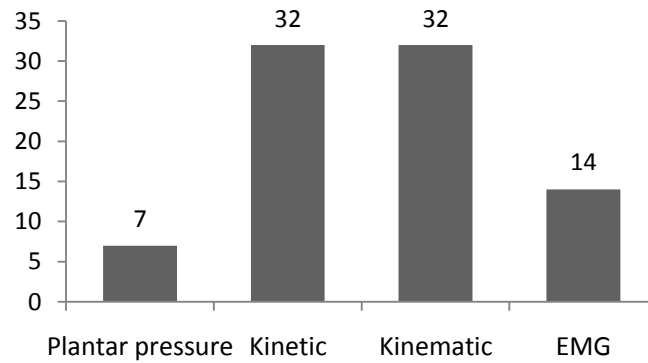


Figure 1.1. Papers distribution by the four biomechanical parameters considered.

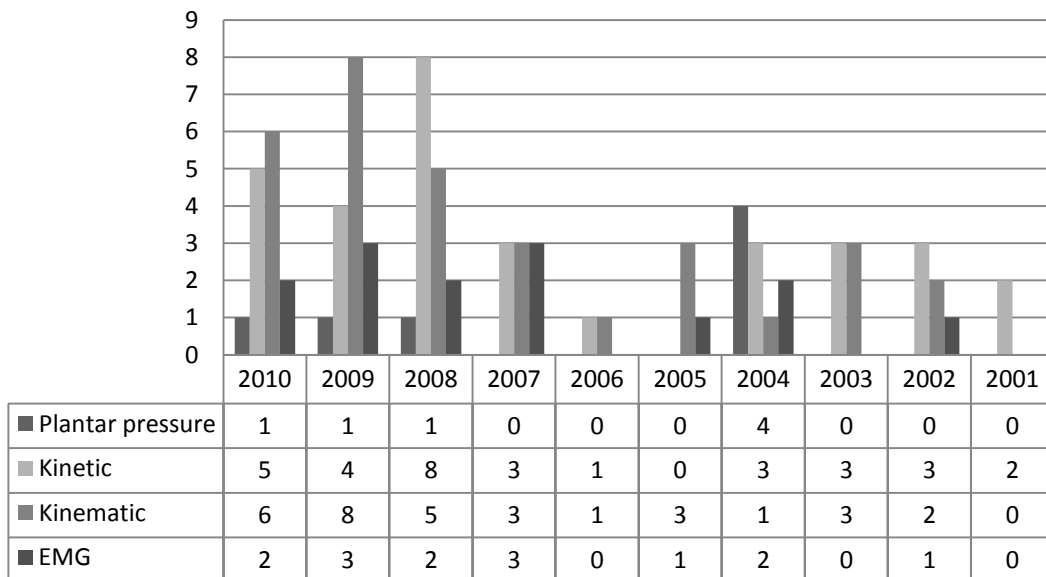


Figure 1.2. Papers distribution across the years also considering the four categories of biomechanical parameters analyzed.

The results are presented in tables, where Tables 1.1 to 1.4 represents the results of the systematic review considering methods and variables (plantar pressure, kinetics, kinematics, EMG), and tables 1.5 to 1.8 the results of the systematic review by reference to results and conclusions.

Table 1.1 presents the output of the systematic literature relative to plantar pressure analysis, considering methods used and variables selected.

**Table 1.1. Systematic review of studies using plantar pressure analysis to depict the effect of gait speed on biomechanical parameters.**

Reference	Methods	Variables
Ho et al. (2010)	PEDAR system insoles	Maximum force Peak pressure
Villaroya et al. (2009)	Pression telemetric system insoles	Time duration of the cycle Time duration of stance phase Time duration of swing phase Peak pressure Mean pressure
Todd et al. (2008)	Footscan 3D system	Peak pressure
Segal (2004)	PEDAR system insoles	Peak pressure
Judith et al. (2004)	PEDAR system insoles	Peak pressure Mean peak pressure Mean maximum force Pressure–time integral Contact area
Taylor et al. (2004)	EMED system pressure platform	Contact time Maximum force Peak pressure Force–time integrals Pressure–time integrals
Gordon et al. (2004)	PEDAR system insoles	Peak pressure Pressure–time integral

In Table 1.1 it can be observed that a total of seven (7) studies used plantar-pressure records to analyze the effect of gait speed on gait relevant biomechanical parameters. Both pressure platforms and insoles were used. Selected variables were a total of eleven (11):

- (i) time duration of the gait cycle;
- (ii) time duration of the stance phase or contact time;
- (iii) time duration of the swing phase;
- (iv) contact area;
- (v) maximum force;
- (vi) mean maximum force;
- (vii) peak pressure;
- (viii) mean peak pressure;
- (ix) mean pressures;

- (x) pressure-time integral;
- (xi) force-time integral.

In most of the studies, the main instrument used was the PEDAR system (Gordon et al., 2004; Ho et al., 2010; Judith et al., 2004; Segal, 2004).

Table 1.2 presents the output of the systematic literature relative to kinetic analysis, considering methods used and variables selected.

**Table 1.2. Systematic review of studies using kinetic analysis to depict the effect of gait speed on biomechanical parameters.**

Reference	Methods	Variables
<b>Meng-Jung &amp; Mao-Jiun (2010)</b>	Two force plates	Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum
<b>Rita (2010)</b>	Treadmill with two force plates	Time duration of stance phase
<b>Caravaggi et al. (2010)</b>	A force plate	Time duration of stance phase Vertical GRF first peak Time to vertical GRF first peak Vertical GRF second peak Time to vertical GRF second peak Vertical GRF intermediate minimum Time to vertical GRF intermediate minimum Anterior-posterior GRF breaking peak Time to anterior-posterior GRF breaking peak Anterior-posterior GRF propulsion peak Time to anterior-posterior GRF propulsion peak
<b>Lewek (2010)</b>	Treadmill with two force plates	Time duration of stance phase Anterior-posterior impulse Peak ankle moment Peak ankle power
<b>Grabowski (2010)</b>	Treadmill with a force plate Footswitches	Stride frequency Contact time Vertical GRF first peak Vertical GRF second peak
<b>Vito et al. (2009)</b>	Two force plates	Peak hip, knee and ankle moment Peak hip, knee and ankle power
<b>Robbins &amp; Maly (2009)</b>	Force plate	Peak knee moment Knee moment impulse

(to be continued)

**Table 1.2. Systematic review of studies using kinetic to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Methods</b>	<b>Variables</b>
<b>Xu et al. (2009)</b>	Instrumented treadmill system	Time duration of the cycle Time duration of single support Time duration of double support Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum
<b>Browning et al. (2009)</b>	Treadmill with a force plate	Step width Mechanical work
<b>Stoquart et al. (2008)</b>	Four strain gauge force transducers	Time duration of stance phase Peak hip, knee and ankle moment Peak hip, knee and ankle power
<b>Saha et al. (2008)</b>	Six force plates	Time duration of single support Time duration of double support Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum
<b>Michael et al. (2008)</b>	Four force plates	Time duration of stance phase Time duration of double support Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum Anterior-posterior GRF breaking peak Anterior-posterior GRF propulsion peak Peak hip, knee and ankle moment Peak hip, knee and ankle power
<b>Teixeira-Salmela et al. (2008)</b>	Three force plates	Peak hip, knee and ankle power Mechanical work
<b>Orendurff et al. (2008)</b>	Two force plates	Anterior-posterior GRF breaking peak Anterior-posterior GRF propulsion peak Peak ankle moment Peak ankle power
<b>Colné et al. (2008)</b>	A force plate	Time duration of double support
<b>Seeley et al. (2008)</b>	Two force plates	Vertical impulse Anterior-posterior impulse
<b>Hreljac et al. (2008)</b>	A force plate	Peak knee and ankle moment Peak knee and ankle power

(to be continued)

**Table 1.2. Systematic review of studies using kinetic to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Methods</b>	<b>Variables</b>
<b>Chiu &amp; Wang (2007)</b>	A force plate	Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum
<b>Jordan et al. (2007)</b>	Treadmill with two force plates	Stride and step length Stride and step time duration Vertical GRF first peak Time to vertical GRF first peak Vertical impulse Contact time
<b>Kimberlee et al. (2007)</b>	Treadmill with two force plates	Stride and step length Stride and step time duration Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum Vertical impulse
<b>Rao et al. (2006)</b>	Six force plates	Peak hip, knee and ankle moment
<b>Bishop et al. (2004)</b>	Two force plates	First anterior-posterior GRF peak
<b>Biewener et al. (2004)</b>	A force plate	Peak hip, knee and ankle moment
<b>Tammy &amp; Mark (2004)</b>	Treadmill with two force plates	Step length Step width Step time duration
<b>LaFiandra et al. (2003)</b>	Treadmill with a force plate	Stride length Stride frequency
<b>Goble et al. (2003)</b>	A force plate	Vertical GRF first peak Time to vertical GRF first peak Vertical GRF second peak Time to vertical GRF second peak Vertical GRF intermediate minimum Time to vertical GRF intermediate minimum Anterior-posterior GRF breaking peak Time to anterior-posterior GRF breaking peak Anterior-posterior GRF propulsive peak Time to anterior-posterior GRF propulsive peak Time duration of stance phase
<b>Lelas et al. (2003)</b>	Two force plates	Peak hip, knee and ankle moment Peak hip, knee and ankle power
<b>Hsiang &amp; Chang (2002)</b>	Treadmill with two force plates	Vertical GRF first peak Vertical GRF second peak Vertical GRF intermediate minimum

**(to be continued)**

**Table 1.2. Systematic review of studies using kinetic to depict the effect of gait speed on biomechanical parameters (continuation).**

Reference	Methods	Variables
LaFiandra et al. (2002)	A force plate	Peak lower body moment
Masani e tal. (2002)	Treadmill with four three-dimensional piezoelectric sensors	Vertical GRF first peak Vertical GRF second peak Medial-lateral GRF first peak Anterior-posterior GRF breaking peak Anterior-posterior GRF propulsive peak
Funato et al. (2001)	Two force plates	Mean horizontal GRF
Riley et al. (2001)	Two force plates	Peak hip, knee and ankle moment Peak hip, knee and ankle power

Table 1.2 showed that almost all the papers – twenty nine (29) in a total of thirty two (32) – used force plates to determine gait kinetic parameters, like GRF, moments or powers. Selected variables were a total of twenty six (26):

- (i) vertical GRF first peak;
- (ii) time to vertical GRF first peak;
- (iii) vertical GRF second peak;
- (iv) time to vertical GRF second peak;
- (v) vertical GRF intermediate minimum;
- (vi) time to vertical GRF intermediate minimum;
- (vii) anterior-posterior GRF breaking peak;
- (viii) time to anterior-posterior GRF breaking peak;
- (ix) anterior-posterior GRF propulsive peak;
- (x) time to anterior posterior GRF propulsive peak;
- (xi) medial-lateral GRF first peak;
- (xii) mean horizontal GRF;
- (xiii) vertical impulse;
- (xiv) anterior-posterior impulse;
- (xv) peak joint moment;
- (xvi) peak joint power;
- (xvii) mechanical work;
- (xviii) moment impulse;
- (xix) stride frequency;
- (xx) stride or step time duration;
- (xxi) stride or step length;
- (xxii) step width;
- (xxiii) time duration of gait cycle;

- (xxiv) time duration of single support;
- (xxv) time duration of double support;
- (xxvi) time duration of stance phase or contact time.

In the kinetic analysis the most common variables were the GRF peaks – vertical and anterior-posterior – and it is on its basis that can be deduced several of the others analyzed variables, as the moments, powers and impulses.

With exclusion of a single study, where a strain gauge was used (Stoquart et al., 2008) in all the others, the force plate was the main measuring instrument used.

Table 1.3 presents the output of the systematic literature relative to kinematic analysis, considering the methods used and variables selected.

**Table 1.3. Systematic review of studies using kinematics to depict the effect of gait speed on biomechanical parameters.**

Reference	Methods	Variables
<b>Meng-Jung &amp; Mao-Jiun (2010)</b>	Optoelectronic system	Hip, knee and ankle joint motion
<b>Riley et al. (2010)</b>	Optoelectronic system Inverse kinematics	Hip joint motion Pelvis motion
<b>Caravaggi et al. (2010)</b>	Optoelectronic system Inverse kinematics	Foot joint motion
<b>Dubbeldam et al. (2010)</b>	Videogrametry system	Stride and step length Stride time duration Stride width Time duration of double support Foot and ankle joint motion
<b>Lewek (2010)</b>	Optoelectronic system	Step length
<b>Caekenberghe et al. (2010)</b>	Videogrametry system Optoelectronic system	Step frequency Step length Time duration of flight phase
<b>Franz et al. (2009)</b>	Optoelectronic system	Stride length Hip joint motion Pelvis and thigh motion
<b>Foissac et al. (2009)</b>	Accelerometers	Trunk motion
<b>Manor et al. (2009)</b>	Videogrametry system	Stride time duration Hip, knee and ankle joint motion
<b>Vito et al. (2009)</b>	Optoelectronic system	Stride length Time duration of stance phase Peak hip, knee and ankle joint motion
<b>Tulchin (2009)</b>	Optoelectronic system Lateral radiographs	Time duration of double support Time duration of single support Time duration of stance phase Ankle and foot joint motion
<b>Shung et al. (2009)</b>	Accelerometers	Peak spine and tibia acceleration
<b>Pierrynowski (2009)</b>	Optoelectronic system	Walking effort
<b>Kong &amp; De Heer (2009)</b>	Optoelectronic system	Stride frequency Stride length and length relative to height Time duration of stance phase
<b>Stoquart et al. (2008)</b>	Optoelectronic system	Step frequency Hip, knee and ankle joint motion

(to be continued)

**Table 1.3. Systematic review of studies using kinematics to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Methods</b>	<b>Variables</b>
<b>Saha et al. (2008)</b>	Optoelectronic system Biofeedtrak	Step length Hip, knee and ankle joint motion
<b>Michael et al. (2008)</b>	Optoelectronic system	Hip, knee, ankle and foot joint motion Trunk and pelvis motion
<b>Sharpe et al. (2008)</b>	Optoelectronic system	Trunk and pelvis motion Relative phase between trunk and pelvis
<b>Orendurff et al. (2008)</b>	Optoelectronic system	Step length
<b>Chiu &amp; Wang (2007)</b>	Optoelectronic system	Hip, knee and ankle joint motion Lumbar motion
<b>Paschalis et al. (2007)</b>	Optoelectronic system	Hip, knee and ankle joint motion Pelvis motion
<b>Olivier &amp; Cretual (2007)</b>	Optoelectronic system High-resolution cameras	Radius of curvature
<b>Hanlon &amp; Anderson (2006)</b>	Videogrametry system	Knee and ankle joint motion
<b>Van Emmerik et al. (2005)</b>	Optoelectronic system	Stride time duration Time duration of swing phase Time duration of stance phase Head, trunk and pelvis motion
<b>Saunders et al. (2005)</b>	Optoelectronic system	Lumbar and pelvis motion
<b>Lee et al. (2005)</b>	Optoelectronic system Inverse dynamics	Stride length Hip joint motion Pelvis motion
<b>Dierick et al. (2004)</b>	Force plate	Amplitude of centre of mass
<b>LaFiandra et al. (2003)</b>	Optoelectronic system	Hip joint motion Trunk and pelvis motion
<b>Holt et al. (2003)</b>	Optoelectronic system	Knee joint motion Amplitude of centre of mass
<b>Lelas et al. (2003)</b>	Optoelectronic system Inverse dynamics	Hip, knee and ankle joint motion
<b>Ivanenko et al. (2002)</b>	Optoelectronic system	Time duration of stance phase Stride length
<b>LaFiandra et al. (2002)</b>	Optoelectronic system	Thoracic and pelvis angular acceleration

In kinematic studies, it was possible to find, beside joint motion analysis, the study of general gait parameters, like stance time, step length and width, double and single support time, etc. Video or light reflection motion analyze systems were the most common methods, which were used in twenty nine (29) out of thirty two (32) papers. Selected variables were a total of sixteen (16):

- (i) segment and joint motion;
- (ii) peak acceleration;
- (iii) angular acceleration;

- (iv) relative phase (difference in time between the peaks of the two segments angles within each stride cycle);
- (v) radius of curvature;
- (vi) walking effort;
- (vii) amplitude of centre of mass;
- (viii) stride or step frequency;
- (ix) stride time duration;
- (x) stride or step length;
- (xi) stride width;
- (xii) time duration of single support;
- (xiii) time duration of double support;
- (xiv) time duration of flight phase;
- (xv) time duration of swing phase;
- (xvi) time duration of stance phase.

Table 1.4 presents the output of the systematic literature relative to EMG analysis, considering methods used and variables selected.

**Table 1.4. Systematic review of studies using electromyographic analysis to depict the effect of gait speed on biomechanical parameters.**

Reference	Methods	Variables
<b>Meng-Jung &amp; Mao-Jiun (2010)</b>	Bipolar surface electrodes	EMG activity of <i>biceps femoris</i> , <i>rectus femoris</i> , <i>tibialis anterior</i> , and <i>medial gastrocnemius</i>
<b>Lewek (2010)</b>	Active surface electrodes	Muscle activity of <i>soleus</i> and medial and lateral <i>gastrocnemius</i>
<b>Schmitz et al. (2009)</b>	Pre-amplified single differential surface electrodes	EMG activity of <i>soleus</i> , <i>gastrocnemius</i> , <i>biceps femoris</i> , <i>medial hamstrings</i> , <i>tibialis anterior</i> , <i>vastus lateralis</i> , and <i>rectus femoris</i>
<b>Kang &amp; Dingwell (2009)</b>	Bipolar surface electrodes	EMG linear envelopes of <i>vastus lateralis</i> , <i>biceps femoris</i> , <i>medial gastrocnemius</i> , and <i>tibialis anterior</i>
<b>Shung et al. (2009)</b>	Surface electrodes	Average EMG values of <i>tibialis anterior</i> , <i>vastus lateralis</i> , and <i>erector spinae</i>
<b>Stoquart et al. (2008)</b>	Telemetry EMG system with surface electrodes	Muscle activity time and duration of <i>quadriceps femoris</i> , <i>biceps femoris</i> , <i>tibialis anterior</i> and <i>lateral gastrocnemius</i>
<b>Michael et al. (2008)</b>	Surface electrodes	Muscle activity of <i>rectus femoris</i> , <i>medial and lateral hamstrings</i> , <i>anterior tibialis</i> and <i>medial gastrocnemius</i>

(to be continued)

**Table 1.4. Systematic review of studies using electromyographic analysis to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Methods</b>	<b>Variables</b>
<b>Chiu &amp; Wang (2007)</b>	Wireless EMG system using bipolar surface electrodes	EMG activity of <i>bilateral lumbar erectors spinae, biceps femoris, rectus femoris, medial gastrocnemius</i> and <i>tibialis anterior</i>
<b>Chumanov et al. (2007)</b>	Pre-amplified single differential surface electrodes	EMG activities of <i>biceps femoris, medial hamstrings, vastus lateralis, rectus femoris,</i> and <i>medial gastrocnemius</i>
<b>Ishikawa et al. (2007)</b>	Bipolar surface electrodes	Pre-activation of <i>medial gastrocnemius</i> Braking phase EMG activity <i>medial gastrocnemius</i> Push-off phase EMG activity <i>medial gastrocnemius</i>
<b>Saunders et al. (2005)</b>	Fine-wire electrodes and surface electrodes	EMG activity of <i>multifidus</i> deep and superficial fascicles, <i>obliquus externus</i> and <i>internus abdominis,</i> <i>transversus abdominis,</i> <i>rectus abdominis</i> and, <i>erector spinae</i>
<b>Bishop et al. (2004)</b>	Surface electrodes	Muscle activity of <i>gluteus medius, hamstring</i> and, <i>soleus muscles</i> Relative EMG timing of <i>gluteus medius, hamstring</i> and, <i>soleus muscles</i>
<b>Gordon et al. (2004)</b>	Surface electrodes	EMG activity of <i>tibialis anterior</i> and <i>medial gastrocnemius</i>
<b>Ivanenko et al. (2002)</b>	Surface electrodes	EMG activity of <i>gluteus maximus, vastus lateralis, rectus femoris, biceps femoris, tibialis anterior,</i> and <i>lateral gastrocnemius</i>

A total of fourteen (14) papers were included in this category of biomechanical variables, most of them used surface EMG procedures. Only one study reported data obtained from implanted detection devices (Saunders et al., 2005). Most of the studies were focused on muscle activity of different muscles or muscle groups. The concept of “EMG activity” presented, however, slightly different approaches like average peak, or maximum peak.

Table 1.5 presents the output of the systematic literature relative to plantar pressure analysis, considering results and conclusions.

**Table 1.5. Systematic review of studies using plantar pressure analysis to depict the effect of gait speed on biomechanical parameters.**

<b>Reference</b>	<b>Results/Conclusions</b>
<b>Ho et al. (2010)</b>	With the increase of speed, apart from the medial forefoot and <i>hallux</i> , the peak pressure of all regions was raised significantly Apart from the regions of the <i>hallux</i> and toes, the maximum force increase significantly with increase in speed
<b>Villaroya et al. (2009)</b>	The complete cycle time was clearly shorter during race walking A large increase in the percentage of the swing and a decrease in the percentage of the stance in race walking Peak pressure values were higher during race walking in the rearfoot and in the fourth and fifth metatarsal heads During race walking mean pressure values in the rearfoot were similar to those supported during free-speed walking and were significantly lower in the forefoot, except in the first metatarsal head
<b>Todd et al. (2008)</b>	Peak pressure increase with speed, except in midfoot and forefoot where peak pressure decrease as walking speed increases Positive correlation between peak pressure and speed, except for midfoot and proximal forefoot where there was a negative correlation
<b>Segal et al. (2004)</b>	Significant differences in peak pressure were found in the great toe, heel, central and medial forefoot The lowest values occurred in the lateral forefoot and the highest values in the heel In the central and medial forefoot, peak pressure increased as velocity initially increased, but decreases at the fastest speed Peak pressure and speed were linearly related in the great toe and heel
<b>Judith et al. (2004)</b>	Faster walking resulted in significantly higher peak and mean peak pressure values under the heel, central and medial forefoot, and toes The greatest increases in peak and mean peak pressure occurred under the heel Mean peak pressure decreased under the lateral midfoot with faster walking speeds Pressure–time integrals were significantly lower under all regions of the foot except for the toes with faster walking speeds Maximum force values increased significantly with faster walking velocities Faster walking was associated with a increase in contact area under the lateral toes, but a reduction under the lateral midfoot
<b>Taylor et al. (2004)</b>	With increased walking speeds, contact time decreased at all regions under the foot Maximum force and peak pressure increased at all regions at faster walking speeds, with the exception of the lateral midfoot, medial forefoot and lateral forefoot Force–time and pressure–time integrals were reduced at faster walking speeds, with the exception of loading under the toes
<b>Gordon et al. (2004)</b>	Speed had minimal effects on plantar pressure–time curves, except for the heel and midfoot A linear relationship was found between speed and peak pressures in the heel, medial forefoot and toes The greatest percentage increases in peak pressure as speed increase occurred in the toe regions

In general all the papers, from Table 1.5, are in agreement. Changing walking speed leads to changes in plantar pressure parameters, with an increase of plantar pressure and plantar

force, and a decrease of stance time duration and gait cycle duration in slow gait when compared to fast gait. It is important to note that not all papers divide the foot in the same regions number. The number of foot regions analyzed varied between two (Villaroya et al., 2009) and ten (Todd et al., 2008) in the studies.

Table 1.6 presents the output of the systematic literature relative to kinetic analysis, considering results and conclusions.

**Table 1.6. Systematic review of studies using kinetics to depict the effect of gait speed on biomechanical parameters.**

Reference	Results/Conclusions
<b>Meng-Jung &amp; Mao-Jiun (2010)</b>	Walking speed effects was significant on most of the vertical GRFs Vertical GRF first peak increased as speed increase Vertical GRF intermediate minimum decreased with the increase of walking speed
<b>Rita (2010)</b>	The difference between the start and end of phase thus decreased with increased gait speed
<b>Caravaggi et al. (2010)</b>	Faster gaits were accompanied by shorter stance durations and larger peaks of GRF The time of heel-rise and of positive onset of anterior–posterior GRF decreased with walking speed Vertical GRF first peak and anterior–posterior GRF peaks trend to increase with the increase of speed Vertical GRF intermediate minimum trend to decrease with the increase of speed
<b>Lewek (2010)</b>	As gait speed increased, a significant increase in propulsive impulse was exhibited Ankle joint moment and power generation increased with each increase in gait speed As gait speed increased, there was a significant decrease in time duration of stance
<b>Grabowski (2010)</b>	Vertical GRF first peak was greater when walking faster, but second peak did not significantly change with speed Stride frequency increase as speed increase Contact time decrease with the increase of speed
<b>Vito et al. (2009)</b>	Peak hip extension moment significantly increased with speed Peak knee flexion moment decreased with speed Peak ankle plantar flexor moment increased with speed Peak hip concentric power significantly increased with speed Peak knee power increased with speed Peak ankle generated power increased with speed
<b>Robbins &amp; Maly (2009)</b>	Peak knee adduction moment for the slow condition was greater than fast condition Peak knee adduction moment for the self-selected condition was not different than the slow or fast conditions Knee adduction moment impulse for the slow condition was greater than both the self-selected and fast conditions Knee adduction moment impulse was no different between the self-selected and fast conditions
<b>Xu et al. (2009)</b>	Increasing walking speed, vertical GRF intermediate minimum decreased, but vertical GRF first and second peaks increased As walking speed increases, both single support time and double support time decrease, as well as the cycle time

(to be continued)

**Table 1.6. Systematic review of studies using kinetics to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Results/Conclusions</b>
<b>Browning et al. (2009)</b>	Step width did not change significantly with walking speed Total positive external mechanical work and negative mechanical work increased as speed increased Both positive external mechanical work of trailing limb and negative external mechanical work of leading leg increased with walking speed
<b>Stoquart et al. (2008)</b>	Stance phase duration decreased with increasing speed Peak hip joint moment increased with speed Peaks knee joint moment increased with speed Peak ankle plantar flexor joint moment increased with speed Peaks hip joint power increased with speed Peaks knee joint power increased with speed Peak ankle generated joint power increased with speed
<b>Saha et al. (2008)</b>	Single support time increased with speed while double support time decreased Vertical GRF first and second peaks increased with walking speed Vertical GRF intermediate minimum decreased with speed
<b>Michael et al. (2008)</b>	Stance phase and double support both decrease steadily with increasing speed Vertical and anterior-posterior GRF peaks increased with increase of speed, while vertical GRF intermediate minimum decreased Peak hip and knee extension/flexion moment increased with speed, as well as peak ankle plantar flexor moment increased with speed Peak hip, knee and ankle power increased with speed
<b>Teixeira-Salmela et al. (2008)</b>	Peak hip, knee and ankle power trend to higher values as cadence increased Positive mechanical work and negative mechanical work increased as speed increased
<b>Orendurff et al. (2008)</b>	Breaking and propulsive peak of anterior-posterior GRF increased with speed Peak ankle moment was greater at faster walking speed Peak ankle power generation was significantly greater during as walking speed increased
<b>Colné et al. (2008)</b>	Double support time decreases when gait speed increases
<b>Seeley et al. (2008)</b>	As speed increase, vertical impulse decreased Anterior-posterior impulse increased with walking speed
<b>Hreljac et al. (2008)</b>	Maximum ankle plantar flexor moment and knee extensor moment increased significantly as gait changed from walk to run Maximum ankle power absorption, knee power absorption, and knee power generation increased significantly with speed
<b>Chiu &amp; Wang (2007)</b>	Walking speed had a significant effect on vertical GRF during the loading response phase and mid-stance phase of a gait cycle Faster walking speed generated a higher first vertical GRF peak and lower vertical GRF intermediate minimum
<b>Jordan et al. (2007)</b>	There was a significant decrease in stride and step time duration, contact time duration, vertical impulse and time to vertical GRF peaks with the increase of speed Vertical GRF first peak increases with speed, as well as step and stride length
<b>Kimberlee et al. (2007)</b>	Vertical impulse, vertical GRF intermediate minimum and stride and step time duration decreased with increasing speed Vertical GRF first and second peaks increased as speed increased, as well as stride and step length

(to be continued)

**Table 1.6. Systematic review of studies using kinetics to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Results/Conclusions</b>
<b>Rao et al. (2006)</b>	Peak hip moment increased with increasing walking speed Peak knee moment increased with speed Peak ankle moment increased as speed increases
<b>Bishop et al. (2004)</b>	Peak braking force of the lead limb increased as cadence increased
<b>Biewener et al. (2004)</b>	With an increase in speed, peak joint moments increased at the hip and at the knee Peak ankle joint moment remained constant as speed increased Decrease in limb mechanical advantage
<b>Tammy &amp; Mark (2004)</b>	Step length increased with speed Step width and time duration decreased as speed increased
<b>LaFiandra et al. (2003)</b>	Stride length as well as stride frequency increased with speed
<b>Goble et al. (2003)</b>	High horizontal velocity significantly increased vertical GRF first and second peaks, as well as anterior-posterior GRF first and second peaks Time to second peak of vertical and anterior-posterior GRF's and time to vertical GRF intermediate minimum increased significantly with horizontal velocity Time to vertical GRF first peak decrease as speed increased and time to anterior-posterior GRF first peak increase, but not significantly Vertical GRF intermediate minimum and stance time decreased significantly as horizontal velocity increased
<b>Lelas et al. (2003)</b>	Peak hip, knee and ankle moment increased as speed increase Peak hip power increased with speed, as well as peak knee power and peak ankle generation power
<b>Hsiang &amp; Chang (2002)</b>	Walking speed generally increase the magnitude of first and second vertical GRF peaks The magnitude of vertical GRF intermediate minimum decreases with increasing walking speed
<b>LaFiandra et al. (2002)</b>	Increases in walking speed were accompanied by increases in lower body moment
<b>Masani et al. (2002)</b>	For vertical and medial-lateral GRF, there was an increasing trend in variability with speed There was a speed at which variability was minimum for anterior-posterior GRF
<b>Funato et al. (2001)</b>	In sprinting, constant increases in velocity were accompanied by increases in horizontal GRF
<b>Riley et al. (2001)</b>	Peak hip, knee and ankle joint moment increased with speed Peak hip and knee joint power increased as well as peak ankle power generation

Table 1.6 shows that an increase or a decrease of walking speed induces changes in both kinetic and general gait parameters, especially GRF curves and peak moments and powers, that increase as speed increases, and time duration of the stance phase, that decreases.

Table 1.7 presents the output of the systematic literature relative to kinematic analysis, considering results and conclusions.

**Table 1.7. Systematic review of studies using kinematics to depict the effect of gait speed on biomechanical parameters.**

<b>Reference</b>	<b>Results/Conclusions</b>
<b>Meng-Jung &amp; Mao-Jiun (2010)</b>	Walking speed effect was significant in hip flexion, hip extension and knee flexion increase of motion The effects of walking speed on ankle joint motion were not so obvious
<b>Riley et al. (2010)</b>	Hip flexion/extension and pelvic tilt ranges of motion increased significantly for running compared to walking
<b>Caravaggi et al. (2010)</b>	Late-stance maximum dorsiflexion increased at all metatarsophalangeal joints with faster gaits The medial longitudinal arch showed a decreased range of motion from foot-flat to heel-rise with increasing walking speed
<b>Dubbeldam et al. (2010)</b>	With decreasing walking speed, stride length decreased while stride time and double-support time increased and stride width remained constant Ankle, medial arch, <i>hallux</i> and rearfoot motion increased as speed increase
<b>Lewek (2010)</b>	As gait speed increased, there was a significant increase in step length
<b>Caekenberghe et al. (2010)</b>	Higher speed was paralleled by a larger step length and a higher step frequency of the transition step in the highest acceleration Increasing the acceleration caused a higher walk-to-run transition speed Flight phase duration was significantly lower for the lowest acceleration
<b>Franz et al. (2009)</b>	Stride length increased considerably from walking to running Thigh extension and pelvic motion were significantly greater during running than walking Hip extension increased from walking to running
<b>Foissac et al. (2009)</b>	A statistically significant increase in vertical displacements of the trunk was seen with increasing speed
<b>Manor et al. (2009)</b>	A significant main effect of speed was present with respect to short- and long-term finite-time Lyapunov exponents and stride duration variability There was no effect of treadmill speed on joint angle variability of the hip, knee, or ankle joints
<b>Vito et al. (2009)</b>	Stride length increased with speed There were no significant differences in stance time and in peak hip, knee and ankle motion
<b>Tulchin (2009)</b>	There was an increase in single support time with increasing walking speed and a decreases in double support time, and stance time With increasing speed, ankle maximal dorsiflexion decreased and maximal plantar flexion increased With speed, rearfoot and forefoot maximal dorsiflexion decreased and maximal plantar flexion increased
<b>Shung et al. (2009)</b>	The peak acceleration always increased at tibia and spine as the walking speed increased Running presented significantly higher values of peak acceleration as compared with walking
<b>Pierrynowski (2009)</b>	There are several simple biomechanical measures of walking effort that are strongly associated with walking speed
<b>Kong &amp; De Heer (2009)</b>	As speed increased, stance time decreased while stride frequency, stride length and relative stride length increased
<b>Stoquart et al. (2008)</b>	Step frequency increased with speed Hip extension peak increased with walking speed Knee flexion peaks increased with speed Ankle plantar flexor peak increased as speed increased

(to be continued)

**Table 1.7. Systematic review of studies using kinematics to depict the effect of gait speed on biomechanical parameters (continuation).**

<b>Reference</b>	<b>Results/Conclusions</b>
<b>Saha et al. (2008)</b>	Step length increased as speed increased Hip maximum flexion increased with speed Knee maximum flexion remained constant with increasing speed Ankle maximum dorsiflexion decreased as speed increased, while maximum plantar flexion increased
<b>Michael et al. (2008)</b>	Trunk obliquity and rotation increase as speed increase, while anterior tilt decrease Pelvic and hip movement increase with speed Knee flexion peaks increased with the increase of walking speed Ankle dorsiflexion decrease as speed increase, while plantar flexion increase Foot progression remain constant
<b>Sharpe et al. (2008)</b>	Pelvis–trunk relative phase increased to a significantly greater extent as speed increased Trunk motion decreases as speed increases With increasing velocity pelvic rotation decreased and then increased
<b>Orendurff et al. (2008)</b>	Step length increased with walking speed
<b>Chiu &amp; Wang (2007)</b>	Increased walking speed caused significant increase in lumbar motion Hip, knee and ankle did not have significant differences
<b>Paschalis et al. (2007)</b>	There is an increases of pelvic tilt and no changes in pelvic obliquity and rotation as speed increase Hip flexion increase while hip extension decrease, from walking to running Knee motion increase with speed, as well as ankle motion
<b>Olivier &amp; Cretual (2007)</b>	Speed/curvature relation is not ensured all the time over the locomotor path
<b>Hanlon &amp; Anderson (2006)</b>	The effect of gait speed is angle dependant and also dependant on the phase of the gait cycle First peak knee motion increased as speed increased, while peaks ankle motion decreased
<b>Van Emmerik et al. (2005)</b>	Stride, stance and swing duration significantly decreased with increasing walking speed Pelvis obliquity significantly increased with speed, whereas axial rotation decreased initially, followed by an increase at higher speeds, anterior-posterior tilt did not show any change In trunk, higher walking speeds resulted in significantly increased lateral flexion and decreased flexion-extension and axial rotation At head, higher walking speeds resulted in significant decreases in lateral flexion and axial rotation whereas in flexion–extension there was first a decrease followed by an increase In lumbo-sacral angle, lateral flexion and axial rotation amplitudes increased significantly with higher walking speeds Pelvis-trunk relative phase axial rotation and lateral flexion increased with speed, while flexion/extension decreased
<b>Saunders et al. (2005)</b>	The amplitude but not timing of lumbo-pelvic motion changes with locomotor speed Frontal plane motion increased with faster walking and running speeds With transition from walking to running lumbo-pelvic motion decreased There was a trend for decreased axial rotation with a change from walking to running
<b>Lee et al. (2005)</b>	Stride length increased with walking speed Peak hip extension increases as speed increases Changes in anterior pelvic tilt were not so evident

(to be continued)

**Table 1.7. Systematic review of studies using kinematics to depict the effect of gait speed on biomechanical parameters (continuation).**

Reference	Results/Conclusions
Dierick et al. (2004)	Vertical and the forward amplitude of centre of mass increased with walking speed Lateral amplitude of centre of mass decreased with speed
LaFiandra et al. (2003)	Increasing walking speed was associated with increases in trunk rotation, pelvic rotation and hip excursion
Holt et al. (2003)	There was significant increases in knee excursion as a function of walking speed Vertical amplitude of the centre of mass increased with speed
Lelas et al. (2003)	Peak hip flexion and extension trend to increased with speed Peak knee flexion and extension trend to increased with walking speed Peak ankle planter flexion in loading response and ankle dorsiflexion during mid stance trend to decrease as speed increase, as peak plantar flexion and dorsiflexion during swing trend to increase
Ivanenko et al. (2002)	Stride length significantly increased with speed while stance phase duration decreased
LaFiandra et al. (2002)	Increasing walking speed resulted in increases for pelvic and thoracic angular acceleration

Papers from Table 1.7 are in agreement, with the exception of Kong & De Heer (2009), who did not find differences in time duration of stance when changing speed, while Tulchin (2009), Van Emmerik et al. (2005) and Vito et al. (2009) found a decrease of stance time duration with increasing speed.

In Table 1.8 the output of the systematic literature review relative to EMG analysis, considering results and conclusions, is presented.

**Table 1.8. Systematic review of studies using electromyographic analysis to depict the effect of gait speed on biomechanical parameters.**

Reference	Results/Conclusions
Meng-Jung & Mao-Jiun (2010)	The EMG response in <i>tibialis anterior</i> increased with increasing walking speed The EMG response in <i>rectus femoris</i> increased with increasing walking speed The EMG response in <i>medial gastrocnemius</i> also increased with increasing walking speed The effect of walking speed on <i>biceps femoris</i> was not significant as the other muscle groups
Lewek (2010)	The magnitude of <i>soleus</i> , and <i>medial</i> and <i>lateral gastrocnemius</i> activity significantly increased with each incremental increase in gait speed

(to be continued)

**Table 1.8. Systematic review of studies using electromyographical analysis to depict the effect of gait speed on biomechanical parameters (continuation).**

Reference	Results/Conclusions
<b>Schmitz et al. (2009)</b>	At loading phase, <i>tibialis anterior</i> , <i>soleus</i> , <i>biceps femoris</i> , and <i>rectus femoris</i> activities increased as speed increased At mid-stance, <i>gastrocnemius</i> and <i>biceps femoris</i> activities increased as speed increased At terminal stance and pre-swing, <i>tibialis anterior</i> , <i>gastrocnemius</i> , <i>biceps femoris</i> , <i>vastus lateralis</i> , <i>medial hamstring</i> , and <i>rectus femoris</i> activities significantly increased as speed increased At initial swing, only <i>rectus femoris</i> activity significantly increased as speed increased At terminal swing, <i>biceps femoris</i> and <i>medial hamstring</i> activity increased with speed
<b>Kang &amp; Dingwell (2009)</b>	Variability of individual EMG linear envelopes increased with speed in <i>vastus lateralis</i> , <i>biceps femoris</i> and <i>tibialis anterior</i> , except in <i>gastrocnemius</i> Peak EMG amplitudes increased with speed for <i>vastus lateralis</i> , <i>biceps femoris</i> , <i>medial gastrocnemius</i> , and <i>tibialis anterior</i>
<b>Shung et al. (2009)</b>	The EMG of <i>tibialis anterior</i> , <i>vastus lateralis</i> , and <i>erector spinae</i> muscles increased as the speed increased during walking, but this was not observed during running
<b>Stoquart et al. (2008)</b>	Time and duration of activation phases changed with speed The duration of the first burst in <i>quadriceps femoris</i> , <i>biceps femoris</i> and <i>tibialis anterior</i> decreased with speed The end of the first burst in <i>lateral gastrocnemius</i> occurred sooner with speed At the end of stance, <i>tibialis anterior</i> was the only muscle active
<b>Michael et al. (2008)</b>	Changes in EMG were characterized by amplification of peak values with increasing speed in <i>rectus femoris</i> , <i>medial and lateral hamstrings</i> , <i>anterior tibialis</i> and <i>medial gastrocnemius</i>
<b>Chiu &amp; Wang (2007)</b>	Walking faster generated significantly higher EMG response in the lumbar <i>erector spinae</i> , <i>biceps femoris</i> , and <i>medial gastrocnemius</i> muscles EMG response in the <i>rectus femoris</i> and <i>tibialis anterior</i> also increased at fast speed, but not significantly
<b>Chumanov et al. (2007)</b>	The influence of <i>biceps femoris</i> , <i>medial hamstrings</i> , <i>vastus lateralis</i> , <i>rectus femoris</i> , and <i>medial gastrocnemius</i> on <i>hamstring</i> stretch was larger at maximal speed
<b>Ishikawa et al. (2007)</b>	Compared to walking, the <i>medial gastrocnemius</i> average EMGs were greater in the pre-activation and braking phases of running In the push-off phase average EMG of the <i>medial gastrocnemius</i> was greater at walking
<b>Saunders et al. (2005)</b>	With increased running speed there was no change in timing of peak EMG for any muscle EMG activity of <i>multifidus</i> deep and superficial fascicles, <i>obliquus externus</i> and <i>internus abdominis</i> , <i>transversus abdominis</i> , <i>rectus abdominis</i> and, <i>erector spinae</i> increased with speed;
<b>Bishop et al. (2004)</b>	There was no main effect noted for cadence in the relative EMG timing of <i>gluteus medius</i> , <i>hamstring</i> and <i>soleus</i> muscles As cadence increased, the onset of muscular activity occurred closer to heel-strike for <i>gluteus medius</i> , while <i>soleus</i> onset was more rapid after heel-strike
<b>Gordon et al. (2004)</b>	Speed had minimal effects on the shapes of the muscle EMG root-mean-square There is a significant increases in peak EMG RMS from the slowest to the fastest speed for <i>tibialis anterior</i> and <i>medial gastrocnemius</i> muscle In muscle activity, there were changes in mean amplitude with increasing speed
<b>Ivanenko et al. (2002)</b>	Mean activity of <i>gluteus maximus</i> , <i>vastus lateralis</i> , <i>rectus femoris</i> , <i>biceps femoris</i> , <i>tibialis anterior</i> , and <i>lateral gastrocnemius</i> tended to increase exponentially with speed, though the increment was not always monotonic

Relatively to muscle activity – peak muscle activity or mean muscle activity – all papers are in agreement. An increase of speed leads to an increased muscle activity.

## **4. Discussion**

This study aimed to systematize the current state of the art in what concerns the effects of speed on the biomechanics of gait. The idea that gait parameters should change with locomotion speed is easily traduced by the empirical observation that, increasing gait speed from very low to very high, will imply a transition from walking to running; two modes of bipedal locomotion with important differences separating them.

From the meta-analysis of the studies included in the present research it is possible to conclude that most of the approaches were conducted both through kinematical and kinetical approaches. These were well distributed through the ten studied years of scientific publications. Plantar pressure studies were mostly published during the year of 2004, and those dealing with EMG were published mostly during the last four years. Both of the late categories were less prevalent in the beginning of the studied time period.

In continuation we will discuss the contents of each one of the tables separately, first in order to methods and variables and secondly in order to results and conclusions, following the four biomechanical parameters used. We will finish with an integrated discussion of the analyzed body of knowledge.

### **4.1. Discussion of methods and variables**

Plantar pressure methods used in the different reviewed papers were adequate to the variables that they intended to study. Most of the studies from this category have chosen PEDAR system insoles (Gordon et al., 2004; Judith et al., 2004; Segal A, 2004; Ho et al., 2010) or a pressure platform (Taylor et al., 2004; Todd et al., 2008). PEDAR system and pressure platforms allow dividing the footprint in different zones, almost as wanted – some authors divided the foot in eight regions, others in ten, others in five and others in nine – this division of foot depends of the interest regions of the study. Villaroya et al. (2009), however, have used a pressure insoles telemetric system with only six sensors, and due this instrumental limitations, the author refrains to study only two regions of the foot: rearfoot and forefoot.

Peak pressure and maximum force were the two most studied variables in plantar pressure protocols, as well as the time duration of stance. All papers analyzed peak (Gordon et al., 2004; Judith et al., 2004; Segal et al., 2004; Todd et al., 2008; Villaroya et al., 2009; Ho et al., 2010). Other variables, like contact area, force-time integral, time duration of swing or time duration of the gait cycle were not so much explored, or did not present consensus, like pressure-time integral and mean pressure, due to the different methods used – number of foot regions, instruments, etc.

Only one author (Stoquart et al., 2008), used isolated strain gauges to measure kinetic parameters – GRF – , while all the others used force plates. Both methods are appropriated to

measure forces, thus to determine kinetic parameters. However, force plates are widely accepted as the “gold standard” for this purpose in gait analysis, reason why its use is spread worldwide (in fact, only one study used a load cell). Furthermore, it can be said that force plates are very accurate and reliable instruments, reason why the results obtained through this type of instrument are in so close agreement. Vertical and anterior-posterior GRF curves were the most analyzed parameters, as well as gait parameters.

Relatively to the kinematic methods, the most part of the authors made use of optoelectronic motion-capture systems. The exceptions were Foissac et al. (2009) and Shung et al.(2009), who used accelerometers, and Dubbeldam et al. (2010), Hanlon & Anderson (2006) and Manor et al. (2009) that used videogrametry systems. Although both videogrametry and optoelectronic systems are commonly used to capture and study body motion, the optoelectronic systems are considered to be more accurate in laboratory conditions use. Accelerometry was used only in trunk motion and for peak spine and tibia acceleration analysis.

Kinematic analysis becomes difficult in part because most part of variables studied did not present consensual results. This can be explained by the low reliability of some of the methods available. Only variables that present great differences are showed to be in agreement, like general gait parameters such as stride and step frequency, stride and step length, time duration of gait cycle, time duration of stance and time duration of double support phase.

Electromyography is the only method to measure muscle activity. However there are two kind of EMG – surface and implanted EMG electrodes. Only Saunders et al. (2005) used implanted electrodes, and mixed with surface electrodes to allow monitoring also deep and superficial muscles.

## **4.2. Discussion of results and conclusions**

### **4.2.1. Gait parameters**

General gait parameters, like time and displacement, can be studied using plantar pressure, kinetic or kinematic protocols. Most of the gait parameters studied showed to be influenced by speed. For the time duration of a cycle – stride or step –, in general, as walking speed increase this variable decrease (Tammy and Mark, 2004; Van Emmerik et al., 2005; Jordan et al., 2007; Kimberlee et al., 2007; Villaroya et al., 2009; Xu et al., 2009; Dubbeldam et al., 2010). Thus, stride or step frequency, and stride or step length, as well as time duration of the various phases of gait cycle – stance, swing, double support, single support –, are changed by an increase or decrease of speed. As expected, stride (LaFiandra et al., 2003; Grabowski, 2010) and step (Stoquart et al., 2008; Kong and De Heer, 2009; Caekenberghe et al., 2010) frequency increase as speed increases. Stride and step length (Ivanenko et al., 2002; LaFiandra et al., 2003; Tammy and Mark, 2004; Lee et al., 2005; Jordan et al., 2007; Kimberlee et al., 2007;

Orendurff et al., 2008; Saha et al., 2008; Franz et al., 2009; Kong and De Heer, 2009; Vito et al., 2009; Caekenberghe et al., 2010; Dubbeldam et al., 2010; Lewek, 2010) and Vito et al. (2009)), also increase with walking speed, as it was expected. Stride width was also analyzed, but only in some few studies (Tammy and Mark, 2004; Browning et al., 2009; Dubbeldam et al., 2010). According to the latter authors quoted, step width is not influenced by walking speed, despite Tammy & Mark (2004) found that an increase in walking speed lead to a slight, but not significant, decrease of step width. Nevertheless, further research is needed, inclusively regarding the expected role of this parameter in gait dynamical balance.

Relatively to the time duration of the stance phase, almost all papers showed a decrease (Caravaggi et al., 2010; Goble et al., 2003; Grabowski 2010; Ivanenko et al., 2002; Kong & De Heer, 2009; Lewek, 2010; Michael et al., 2008; Rita, 2010; Stoquart et al. 2008; Taylor et al., 2004; Tulchin, 2009; Van Emmerik et al., 2005; Villaroya et al., 2009) with the increase of walking speed, except Vito et al. (2009) who found no significant differences. This discrepancy may be explained by the low differences between the speed intervals studied in the late report, which was determined by the method used to choose gait speed – based on the principle of dynamic similarity. Only Caekenberghe et al. (2010) observed what happens to the flight phase, during running, this increase as acceleration increase.

There was no agreement on the effect of changing walking speed on the time duration of swing phase. To Villaroya et al. (2009), an increase of speed leads to an increasing of time duration of the swing phase normalized to time duration of gait cycle, and to Van Emmerik et al. (2005), the opposite seems to happen. This could be due to the fact that the first author used a plantar pressure protocol to identify the swing phase time duration, while the second used a kinematical approach. Nevertheless, it should be emphasized that both options seem appropriated for the purpose, and further investigation is needed on this particular topic.

As well as time duration of the stance phase, time duration of the double support phase decrease as walking speed increase (Colné et al., 2008; Dubbeldam et al., 2010; Michael et al., 2008; Saha et al., 2008; Tulchin, 2009; Xu et al., 2009). This seems to be completely consensual among literature. The relatively reduced dynamical stability of gait due to the reduced double support phase may contribute to a compensation effect that, in some cases, may be traduced by an increased step width.

The effect of increased gait speed on the time duration of single support time is not consensual. Tulchin (2009) and Saha et al. (2008) described that with an increase of speed, single support duration time also increase. On the other hand, Xu et al. (2009) found that it decrease as walking speed increase. To redeem this controversy, ground reaction forces must also be considered. Indeed, an increased gait speed should be a result of increased impulses, the product of forces by their application time.

#### **4.2.2. Plantar pressure**

The most used variable in plantar pressure studies is peak pressure. This variable was analyzed in all papers that used this kind of protocols (Gordon et al., 2004; Ho et al., 2010; Judith et al., 2004; Segal, 2004; Taylor et al., 2004; Todd et al., 2008; Villaroya et al., 2009). Each paper divided the foot in a different number of areas to study, Villaroya et al. (2009) was the only that divide the foot in rearfoot and forefoot. The others divided the foot in five (Segal, 2004), eight (Ho et al., 2010; Judith et al., 2004), nine (Gordon et al., 2004; Taylor et al. 2004) and ten (Todd et al., 2008) regions. The most studied foot regions are the *hallux*, the forefoot and the heel. In general, all papers considered that peak pressure increased significantly at heel, toes and *hallux* as speed increases – except for Ho et al. (2010) who observed that at the *hallux*, the increase in peak pressure with speed is not statistically significant. Medial and central forefoot peak pressure increased significantly and consensually with increasing walking speed (Gordon et al., 2004; Ho et al., 2010; Judith et al., 2004; Segal, 2004; Taylor et al., 2004). Lateral forefoot and midfoot peak pressure results present some disagreements among published studies. Todd et al. (2008) considers that there is a decrease of peak pressure at these two foot regions. However, for Ho et al. (2010) and Taylor et al. (2004), there is an increase, and for Gordon et al. (2004) and Judith et al. (2004) – and Segal (2004) at the lateral forefoot –, there is no changes in peak pressure attributable to gait speed variations. More studies are needed to clarify this issue.

Judith et al. (2004) also analyzed the mean peak pressure. Their findings were similar to those obtained for peak pressure. With gait speed increases, mean peak pressure increases at *hallux*, toes, heel, and central and medial forefoot, and remain unchanged at midfoot and lateral forefoot. On the other hand, Villaroya et al. (2009) presents lower values of mean pressure at the forefoot as walking speed increases. This incongruence may be due to the fact that Judith et al. (2004) used Pedar system insoles (with 99 capacitive sensors) and Villaroya et al. (2009) used a Pressure insoles telemetric system (with 6 piezoresistive sensors).

Pressure-time integral was studied by several authors (Gordon et al., 2004; Judith et al., 2004; Taylor et al., 2004; Gordon et al., 2004) concluded that speed affect significantly pressure-time distribution shape at the heel and midfoot. As walking speed increase pressure-time integral at heel, midfoot and forefoot – central, medial and lateral – decreased, and at *hallux* and toes there is no significant change (Judith et al., 2004; Taylor et al., 2004). These findings agree with the assumption that the forces applied in the plane of the ground (anterior-posterior) are the ones that most contribute to gait acceleration (this is in line with the GRF data to be discussed ahead). Moreover, the reduced pressure-time integral at the heel should be related to an increased contact area with speed, and/or to a reduced contact time, once, as we will see, the first peak value of the vertical component of the GRF seem to increase with speed.

In accordance, force (vertical)-time integral, same as pressure-time integral, decrease at all foot regions – heel, midfoot and forefoot – except at *hallux* and toes (Taylor, et al., 2004).

Maximum force and mean maximum force, as well as the peak pressure, increase in almost all foot regions. All the authors (Ho et al., 2010; Judith et al., 2004; Taylor et al., 2004) are in agreement relatively to maximum force at heel, which increases significantly with speed. To *hallux* and toes, authors also found that there is an increase (Judith et al., 2004; Taylor et al., 2004), but not statistically significant (Ho et al., 2010). According to Judith et al. (2004) and Taylor et al. (2004), maximum force at medial and lateral midfoot remain constant as speed increase, as well as at the lateral forefoot. To medial and central forefoot, Ho et al. (2010) found an increase of this variable with speed, while Judith et al. (2004) show that central forefoot maximum force remains unchanged and that there is an increase in medial forefoot, while Taylor et al. (2004) demonstrate the opposite – medial forefoot maximum force remain unchanged and central forefoot increase as speed increase. Once more, new approaches should be conducted to clarify these effects.

Only one study (Taylor et al., 2004) reports information about the effect of gait speed on the extension of the foot to ground contact area. In this study it is stated that contact area decrease at lateral midfoot, increase at toes and is unchanged at the remaining foot areas as gaits speed increase.

#### **4.2.3. Kinetics**

All papers are in agreement in what concerns the effect of walking speed on vertical GRF peaks, intermediate minimum (Caravaggi et al., 2010; Chiu & Wang, 2007; Goble et al., 2003; Grabowski, 2010; Hsiang & Chang, 2002; Jordan et al., 2007; Kimberlee et al., 2007; Meng-Jung & Mao-Jiun, 2010; Michael et al., 2008; Saha et al., 2008; Xu et al., 2009) and correspondent times of occurrence (Caravaggi et al., 2010; Jordan et al., 2007; Goble et al., 2003). As speed increases, vertical GRF first peak increase significantly while vertical GRF second peak did not show significant differences, and vertical GRF intermediate minimum decreases significantly. Time to vertical GRF first peak decreases significantly, while time to vertical GRF intermediate minimum and time to vertical GRF second peak increase significantly.

Both, breaking and propulsive, anterior-posterior GRF peaks increase significantly with walking speed (Bishop et al., 2004; Caravaggi et al., 2010; Goble et al., 2003; Michael et al., 2008; Orendurff et al., 2008). In accordance to Goble et al. (2003), the time to both anterior-posterior GRF peaks – breaking and propulsive – increase with walking speed. However Caravaggi et al. (2010) found no change in these parameters as speed increase. The increase with gait speed of the anterior-posterior GRF peaks can also be observed in the mean values of the two horizontal components of the GRF – anterior-posterior and medial-lateral. In fact, both of this two GRF components increase as speed increase (Funato, et al., 2001).

Masani et al. (2002) analyzed the variability of GRF curves – vertical, anterior-posterior and medial-lateral – as speed increases. They found that variability of vertical and medial-lateral GRF increase as speed increase, while, on the other hand, anterior posterior GRF presents a critical speed at which the variability is minimal. With these results, Masani et al. (2002) suggest that there is an optimum speed for propulsion control mechanism.

Based on vertical and anterior-posterior GRF, there is another relevant variable frequently analyzed by the different research groups: the impulse (vertical or anterior-posterior). Vertical impulse and anterior-posterior impulse seem to have opposite behavior. The first one decreases significantly (Jordan et al., 2007; Kimberlee et al., 2007; Seeley et al., 2008) as speed increases, while the second one increases significantly (Lewek 2010; Seeley et al., 2008). The impulse of a force is both determined by its intensity and by the time duration of its application. As a consequence, the high vertical impulse values characteristic of slow gait may probably be explained by the higher stance phase duration rather than force intensity. Meanwhile, horizontal impulses may be related to shear stress applied to the contact surfaces (plantar surface of the feet), possibly explaining blister development (Birrell et al., 2007).

Peak moments are analyzed at lower limb, hip, knee and ankle. Peak lower limb moment increase as walking speed increases (LaFiandra et al., 2002), and peak hip and knee (Biewener et al., 2004; Lelas et al., 2003; Rao et al., 2006; Riley et al., 2001; Stoquart et al., 2008), as well as peak ankle moment (Lelas et al., 2003; Lewek, 2010; Orendurff et al., 2008; Rao et al. 2006; Riley et al., 2001), in general, also increase with speed. Vito et al. (2009) and Michael et al. (2008) found that there is a significant increase in hip extension moment with speed. Peak knee flexion (Hreljac et al., 2008; Michael et al., 2008; Vito et al., 2009) and adduction (Robbins & Maly, 2009) decrease as speed increase. Concerning peak ankle moment, although there is one study that reports no changes (Biewener et al., 2004), several others (Hreljac et al., 2008; Vito et al., 2009; Michael et al., 2008; Stoquart et al., 2008) found an increase of plantar flexor moment with gait speed, which seem to be coherent with the increase of anterior-posterior horizontal GRF values.

Beyond knee moment, there is one study that analyzes knee moment impulse (Robbins & Maly, 2009). As speed increase, this variable decrease, once more mainly because of the decrease observed in stance phase duration at fast gait.

Same to peak joint moments, peak joint power values are analyzed at hip, knee and ankle. All the papers reported an increase of peak hip power (Lelas et al., 2003; Michael et al., 2008; Riley et al., 2001; Stoquart et al., 2008; Teixeira-Salmela et al., 2008). Vito et al. (2009) are more specific and reported a significant increase at hip concentric power as speed increases. As well as hip, peak knee power present higher values as speed increases (Hreljac et al., 2008; Lelas et al., 2003; Michael et al., 2008; Riley et al., 2001; Stoquart et al., 2008; Teixeira-Salmela et al., 2008; Vito et al., 2009). In general, peak ankle power increase with speed (Michael et al.,

2008; Teixeira-Salmela et al., 2008). The most reported change is the increase of peak ankle power generation (Lelas et al., 2003; Lewek 2010; Orendurff et al., 2008; Riley et al., 2001; Stoquart et al., 2008; Vito et al., 2009), although peak ankle power absorption also increase with speed (Hreljac et al., 2008).

Mechanical work of lower limb has been studied by Browning et al. (2009) and Teixeira-Salmela et al. (2008). Both paper's findings are expectable and in agreement: mechanical work, positive or negative, increase as speed increase.

#### **4.2.4. Kinematics**

Kinematic study consists essentially in joint motion analysis – hip, knee, ankle and foot – and segment motion analysis – head, trunk, lumbar, pelvis and thigh.

At head, it was observed a significant decrease in lateral flexion and axial rotation when speed increases (Van Emmerik et al., 2005). Meanwhile, Sharpe et al. (2008) found that trunk motion decreases as speed increases. Michael et al. (2008) and Van Emmerik et al. (2005), in accordance, reported, respectively, a decrease in trunk tilt and a decrease in flexion-extension motion. Despite that, a significant increase of vertical displacements of trunk was observed by Foissac et al. (2009). Obliquity (Michael et al., 2008) and lateral-flexion (Van Emmerik et al., 2005) of the trunk also increased as speed rises. Regarding trunk rotation, some disagreements were perceived in the studied literature that justify further research: on one hand LaFiandra et al. (2003) and Michael et al. (2008) found an increase in trunk rotation and, on the other, Van Emmerik et al. (2005) observed that axial rotation decrease with the increase of walking speed. Thigh extension motion increase as speed increases (Franz et al., 2009).

In general, pelvis motion increase significantly with speed (Franz, et al., 2009; Michael, et al., 2008), as well as lumbar motion (Chiu & Wang, 2007). There is no consensus in pelvic tilt, rotation and obliquity motion and further approaches are needed. For Paschalis et al. (2007) and Riley et al. (2010), pelvic tilt increase with speed, whereas for Lee et al. (2005) and Van Emmerik et al. (2005) it remains unchanged. Concerning pelvic obliquity, Paschalis et al. (2007) did not note any change, and Van Emmerik et al. (2005) found a significant increase with speed. Relatively to pelvic rotation, some authors reported no observed change (Paschalis et al., 2007), while others stated that there is an increase (LaFiandra et al., 2003) and, finally, others found a decrease followed by a subsequent increase (Sharpe et al., 2008; Van Emmerik et al., 2005). Again, new insight is needed.

Disagreements were also found concerning general hip movement. Some studies stated that there is no significant changes with speed (Chiu & Wang, 2007; Vito et al., 2009) while LaFiandra et al. (2003) found an increased movement. Several authors (Lelas et al., 2003; Meng-Jung & Mao-Jiun, 2010; Michael et al., 2008; Paschalis et al., 2007; Riley et al., 2010; Saha et al., 2008) agree that hip flexion increases as walking speed increases; however, some

other disagree about hip extension motion: to Lee et al. (2005), Lelas et al. (2003), Meng-Jung & Mao-Jiun (2010), Michael et al. (2008), Riley et al. (2010) and Stoquart et al. (2008) there is an increase of hip extension motion, while Paschalis et al. (2007) observed a decrease and Franz et al. (2009) found no significant changes. This discrepancy among the author's observations may be due to the walking speeds chosen; Paschalis et al. (2007), only studied two different speeds, which were much higher than those used by the others authors.

Saunders et al. (2005) report a decrease of axial rotation of lumbar-pelvic motion with the increase of speed.

In general, authors agree that knee flexion motion increase (Hanlon & Anderson, 2006; Holt et al., 2003; Lelas et al., 2003; Meng-Jung & Mao-Jiun, 2010; Michael et al., 2008; Paschalis et al., 2007; Stoquart et al., 2008) with the increase of walking speed. Only Saha et al. (2008) found that knee motion remain unchanged, while others (Chiu & Wang, 2007; Manor et al., 2009; Vito et al., 2009) refer that there is no significant change.

As well as in most of the joint kinematics previously discussed, it seems that there are disagreements in literature results relatively to ankle motion, also justifying a deeper and extensive study. Dubbeldam et al. (2010) and Paschalis et al. (2007) found that ankle motion increases with speed, but the opposite, a decrease of ankle motion, was described by Hanlon & Anderson (2006), Chiu & Wang (2007), Manor et al. (2009) and Meng-Jung & Mao-Jiun (2010). Vito et al. (2009) did not find any significant changes. Dorsiflexion motion decrease (Michael, et al., 2008; Saha, et al., 2008; Tulchin, 2009) while plantar flexor increase (Michael et al., 2008; Saha et al., 2008; Stoquart et al., 2008; Tulchin 2009) as speed increase. Meanwhile, Lelas et al. (2003) noted that, during the swing phase, both plantar flexion and dorsiflexion increase, while during stance phase this two movements decrease.

Foot joint motion does not change significantly with speed (Michael, et al., 2008). There are some disagreements between studies, when analyzing the different foot regions separately. For Dubbeldam et al. (2010), medial arch motion increases as speed increases, but the same do not happen in the results obtained by Caravaggi et al. (2010). Rearfoot motion increases with speed (Dubbeldam, et al., 2010), but with a possible slight decrease of rearfoot dorsiflexion and an increase of plantarflexion (Tulchin 2009). Tulchin (2009) found a similar behavior of forefoot motion – a decrease of dorsiflexion motion and an increase of plantar flexion motion –, but Caravaggi et al. (2010) reported that forefoot dorsiflexion increase as walking speed increase. Only Dubbeldam et al. (2010) analyzed *hallux* and found an increase of motion with speed.

Sharpe et al. (2008) and Van Emmerik et al. (2005) analyze trunk-pelvic relative phase. A significant increase of it was observed by Sharpe et al. (2008). This findings can be explained by the increase of continuous relative-phase of pelvic-trunk axial rotation and lateral flexion

(Van Emmerik et al., 2005) that can be seen as speed increase, although there is a decrease of continuous relative-phase of pelvic-trunk extension-flexion (Van Emmerik et al., 2005).

Centre of mass amplitudes of movement has also been studied (Dierick et al., 2004; Holt et al., 2003). Both studies found an increase of vertical amplitude as speed increase, but Dierick et al. (2004) also found that forward amplitude increases and lateral amplitude decreases.

Only one study about each one of the following variables was found: peak acceleration, angular acceleration, radius curvature or walking effort. Peak acceleration was studied by Shung et al. (2009) at tibia and spine and angular acceleration by LaFiandra et al. (2002) at pelvis and thorax. From these contributions, it seems that increasing walking speed leads to an increase of these variables. Speed-curvature, i.e. radius of curvature, relation was studied by Olivier & Cretual (2007), which reported that this relationship is not ensured all the time, meaning that speed can influence radius curvature, but it is not the main factor. Pierrynowski (2009) analyzed the influence of walking speed on walking effort and found that, as it was expected, there is a strong association between these two parameters. In this study, walking effort was measured with several methods – using a compass method, a space curve displacement, a space curve acceleration and differential geometry.

#### **4.2.5. Electromyography**

In general, it is possible to state that the speed changing implies changes on muscle activation – amplitudes, timing and duration. *Vastus lateralis*, *rectus femoris*, *biceps femoris*, *medial* and *lateral hamstrings*, *tibialis anterior*, *medial* and *lateral gastrocnemius*, *gluteus maximus*, *soleus*, *erector spinae*, *multifidus*, *obliquus abdominis*, *transversus abdominis* and *rectus abdominis* have similar behavior: they increase their amplitudes as speed increase (Chiu & Wang, 2007; Chumanov et al., 2007; Gordon et al., 2004; Ivanenko et al., 2002; Kang & Dingwell, 2009; Lewek, 2010; Meng-Jung & Mao-Jiun, 2010; Michael et al., 2008; Saunders et al., 2005; Shung et al., 2009). As well as the amplitudes, *biceps femoris*, *vastus lateralis* and *tibialis anterior* increase their variability with walking speed (Kang & Dingwell, 2009), which means that the increase with the speed is not always the same.

Schmitz et al. (2009) was the only research group that studied the increase of muscle activity along each gait cycle phase as speed increases; however, Stoquart et al. (2008) and Ishikawa et al. (2007) analyzed what happens at the end of stance phase and at breaking and push-off phases, respectively (the last one only studied the *medial gastrocnemius*). From this analysis, it can be understood that the increase of activity with speed is also gait cycle phase dependent. During the loading phase, Schmitz et al. (2009) found that there is an increase of the activation of *tibialis anterior*, *soleus*, *biceps femoris* and *rectus femoris*; to midstance, an increase of *gastrocnemius* and *biceps femoris* activation was observed. Ishikawa et al. (2007) refer that *medial gastrocnemius* increased activity happens during the pre-activation and

braking phases. At terminal stance and pre-swing phase, Stoquart et al. (2008) also found higher activation of *tibialis anterior* and *gastrocnemius*. Meanwhile, for Ishikawa et al. (2007) there is a decrease of *gastrocnemius* activity, while *vastus lateralis*, *medial hamstring* and *rectus femoris* are active; at initial swing only *rectus femoris* increase his active and at terminal swing *biceps femoris* and *medial hamstring*.

Timing of activation of *gluteus medius* and *soleus* occur earlier when walking speed increases (Bishop et al., 2004), and the duration of the activation of *quadriceps femoris*, *biceps femoris* and *tibialis anterior* decrease as speed increases (Stoquart et al., 2008).

Analyzing the results of plantar pressure variables, it is apparent that consensual variables are peak pressure and maximum force. This occurs because the others plantar pressure parameters are not so frequently studied – in most of the cases only one or two papers dealt with each one, emphasizing the urgency of an extended and integrated approach to the problem.

Almost all kinetic variables have consensual results, mainly those concerned to vertical GRF curves (peaks and time to peaks, intermediate minimum and time to intermediate minimum and impulse), anterior-posterior GRF (peaks and impulse), gait parameters (stride and step frequency, stride and step length, time duration of gait cycle, time duration of stance and time duration of double support phase) or moments and powers. Mechanical work also presents consensual results. This is explain because force plate is a very reliable method.

In opposite to kinetic variables, kinematic variables did not show consensual results, only gait general parameters – like stride and step frequency, stride and step length, time duration of gait cycle, time duration of stance and time duration of double support phase – and centre of mass amplitudes showed literature consensus. This may be attributable to the relative accuracy of kinematic methods, but also to biomechanical redundancy and variability of explicit causalities.

Electromiographic results showed that there is a general and expected increase of muscle activity.

It is also interesting to note that, for one variable, different protocols allows reaching the same result. Time duration of gait cycle as well as time duration of stance, for plantar pressure, kinetic and kinematic protocols have the same consensual results. The same happen relatively to stride and step frequency, stride and step length and time duration of double support, for kinetic and kinematic protocols.

## 5. Conclusions

With this review we have systematized the state of the art on the influence of speed in biomechanical parameters that characterize the gait action. Table 1.9 presents a synthesis of the consensual findings. However, other parameters seemed to be differently affected by gait speed in different studies, introducing a controversy that needs further contributions and deeper and extensive research.

**Table 1.9. Influence of speed on consensual variables.**

	<b>Plantar Pressure</b>	<b>Kinetic</b>	<b>Kinematic</b>	<b>EMG</b>
<b>Stride and step frequency</b>	—	↑	↑	—
<b>Stride and step length</b>	—	↑	↑	—
<b>Time duration of gait cycle</b>	—	↓	↓	—
<b>Time duration of stance</b>	↓	↓	↓	—
<b>Time duration of double support phase</b>	—	↓	↓	—
<b>Peak pressure</b>	↑	—	—	—
<b>Maximum force</b>	↑	—	—	—
<b>Vertical GRF first peak</b>	—	↑	—	—
<b>Vertical GRF second peak</b>	—	↑	—	—
<b>Vertical GRF intermediate minimum</b>	—	↓	—	—
<b>Time to vertical GRF first peak</b>	—	↓	—	—
<b>Time to vertical GRF second peak</b>	—	↑	—	—
<b>Time to vertical GRF intermediate minimum</b>	—	↑	—	—
<b>Vertical impulse</b>	—	↓	—	—
<b>Anterior-posterior GRF first peak</b>	—	↑	—	—
<b>Anterior-posterior GRF second peak</b>	—	↑	—	—

(to be continued)

**Table 1.9. Influence of speed on consensual variables. (continuation)**

	<b>Plantar Pressure</b>	<b>Kinetic</b>	<b>Kinematic</b>	<b>EMG</b>
<b>Anterior-posterior impulse</b>	—	↑	—	—
<b>Peak moments</b>	—	↑	—	—
<b>Peak powers</b>	—	↑	—	—
<b>Mechanical work</b>	—	↑	—	—
<b>Centre of mass amplitudes</b>	—	—	↑	—
<b>Muscle activity</b>	—	—	—	↑

Concluding, it can be stressed out that changing gait speed determines important changes in the human biomechanics of this particular locomotion action. A deeper knowledge of these changes may conduce to a better understanding of gait tests and normalization procedures, allowing a better evaluation capability of the gait pathological situations, as well as of the strategies to be implemented for its correction or compensation.

## **Chapter 2 – Original paper**

### ***Influence of walking speed in backpacker's gait on ground reaction forces and plantar pressure parameters***

KEY WORDS: Biomechanics, Gait, Velocity, Overload, Baropodometry, Force plate



## **1. Introduction**

Standing or walking with backpacks raises superiorly the combined centre of mass of the backpack and body, inducing postural imbalance for static and dynamic conditions (Singh and Koh, 2009). It is well known that overload is bad for health, in many ways – either in a physiological perspective, or in anatomical/mechanical one (Ko et al., 2010). When wearing a backpack there is an occasional overload of the musculoskeletal complex, which may lead to adaptation in postures and forces; for example, load carriage causes increased forward lean, increases of impact and shear forces during gait (Birrell and Haslam, 2009).

It is, also, well known that walking speed influences the fundamental elements of gait — joint rotations (kinematics), ground reaction forces (GRF), net internal joint moments and joint power (kinetics), muscle activity as measured by electromyography (EMG), and spatio-temporal parameters such as speed, stride length, and cadence (Michael et al., 2008).

Some authors (Birrell and Haslam, 2009; Singh and Koh, 2009; Xu et al., 2009; Birrell and Haslam, 2010) have studied the influence of these two factors, occasional overload and speed, in gait biomechanical parameters by means of kinetic, kinematic or both methods. The majority of these studies used a kinetic protocol combined with kinematic or plantar pressure protocol individually. The force analysis by means of force plates is considered the most accurate measurement of force (Cobb and Claremont, 1995); however, do not provide information about what happens in specific plantar regions, such the plantar pressure analyze does. This overall approach (GRF plus plantar pressure) about gait kinetics may helps in the development of devices, such as insoles or shoes, as well as the training improvement in order to prevent injuries and implement performance of this high demanding activity. Besides, the influence of the speed during occasional overload is, as far we know, scarce in the literature.

Therefore, the purpose of this study was to investigate the influence of speed during normal gait (unload condition) and backpacker's gait (occasional overload condition) in GRF and plantar pressure parameters during gait.

## **2. Methods**

### **2.1. *Participants***

The sample was selected by convenience from university students of sport science and was composed by 60 subjects (30 male and 30 female) with a mean age of  $23.0 \pm 3.7$  years, mean height of  $168.0 \pm 0.1$  cm and mean body mass of  $67.8 \pm 11.2$  kg. All participants were physically active and did not present a body mass index (BMI) above 25, did not have any traumatic-orthopedic dysfunction and no difficulties on independent gait. The study 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, embedded in the middle of a 6 m walkway 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 (age and height) were recorded. For each participant was calculated the weight to raise their body mass index (BMI) to a value of 30, 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  $20.3 \pm 4.4$  kg). This overload was chosen because it is considered to make the locomotor system more prone to injuries (Ko et al., 2010). It was attached a cuff unit measuring 98 x 64 x 29 mm with Velcro strap up 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 connected to a computer; the cable did not cause any perceivable restriction for the gait development. A pair of thin socks and, aiming minimizes the effects of different soles, neutral shoe (ballet sneaker) with sensor insoles was provided for all participants. During the familiarization, the participants walked freely (without backpack) over the walkway; in this moment the research identified the site where the participant should begin the gait to tramp, with his right foot, in the center of the plate force without altering their gait pattern. In the last phase the participants performed three valid tests without backpack (normal condition which was called as control group – CG) and three valid testes with backpack (overload condition which was called backpacker's group – BpG), where they walked with a slower and a faster speed, 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 the gait pattern to achieve this goal.

## **2.4. Data Analysis**

For the acquisition of force plate and insole pressure system data, the Acknowledge software (BIOPAC System, California, USA) and the software F-Scan Research 6.33 (TekScan, South Boston, USA) were used, respectively. The data from the force plate (three GRF

components) and the insole pressure system (values of each sensor) were exported to Matlab 7.0 software (MathWorks, Massachusetts, USA) and a program was developed to data processing and calculations of the variables analyzed.

Considering force plate data, dependent variables were calculated related to absolute ( $_{Abs}$ ) and normalized to body weight ( $_{Norm}$ ) values and time ( $_{Time}$ ), respectively, for the following events: first peak ( $PkVt_{F\_Abs}$ ,  $PkVt_{F\_Norm}$  and  $PkVt_{F\_Time}$ ), intermediate minimum ( $Vt_{Min\_Abs}$ ,  $Vt_{Min\_Norm}$  and  $Vt_{Min\_Time}$ ) and second peak ( $PkVt_{S\_Abs}$ ,  $PkVt_{S\_Norm}$  and  $PkVt_{S\_Time}$ ) of the GRF vertical component; braking (negative) peak ( $PkAP_{B\_Abs}$ ,  $PkAP_{B\_Norm}$  and  $PkAP_{B\_Time}$ ) and propulsive 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 in 10 regions, as proposed and adapted from previous studies (Cavanagh and Ulbrecht, 1994; Gurney et al., 2008). The adaptations were in the rearfoot (RF) where it was divided into three parts (33% each) and in the second toe where it was not differentiated from the 3°, 4° and 5° toes. Therefore, dependent variables were calculated related to absolute and normalized sensor peak and time of occurrence, 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 midfoot (MF) ( $PkMF_{Med\_Abs}$ ,  $PkMF_{Med\_Norm}$  and  $PkMF_{Med\_Time}$ ); lateral MF ( $PkMF_{Lat\_Abs}$ ,  $PkMF_{Lat\_Norm}$  and  $PkMF_{Lat\_Time}$ ); first metatarsal region, called medial forefoot (FF) ( $PkFF_{Med\_Abs}$ ,  $PkFF_{Med\_Norm}$  and  $PkFF_{Med\_Time}$ ); second metatarsal region, called central FF ( $PkFF_{Ct\_Abs}$ ,  $PkFF_{Ct\_Norm}$  and  $PkFF_{Ct\_Time}$ ); lateral metatarsals region, called 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 a percentage of stance phase) also were calculated. The program automatically divided 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 (Woodburn and Helliwell, 1996; Rosenbaum and Becker, 1997; Nicolopoulos et al., 2000), and the force plate are considered to be the most accurate measurement devices of force (Cobb and Claremont, 1995), the force plate was used to calibrate (post-test) the insole pressure system.

## **2.5. 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 Kolmogorov-Smirnov test. Since some variables did not presented normal distribution (59 of 192 variables), in order to standardize the presentation of results, only non-parametric

statistics was performed. Therefore, to compare the variables between slow and fast speeds in CG and between slow and fast speeds in BpG the Wilcoxon test was used. The significance level was  $\alpha = 0.05$ . The results will be presented as median and interquartile range, and the statistical procedures were made using SPSS (v.17; SPSS Inc, Chicago, IL, USA) software.

### 3. Results

Table 2.1 presents the results for statistical analysis of negative and positive Wilcoxon rankings between fast and slow speed either in CG and BpG group for force variables. In CG,  $PkVt_{F\_Abs}$ ,  $PkVt_{F\_Norm}$ ,  $PkVt_{S\_Abs}$ ,  $PkVt_{S\_Norm}$ ,  $PkAP_{B\_Abs}$ ,  $PkAP_{B\_Norm}$ ,  $PkAP_{P\_Abs}$  and  $PkAP_{P\_Norm}$  presented larger magnitudes for fast speed when compared to slow speed. With  $Vt_{Min\_Abs}$  and  $Vt_{Min\_Norm}$ , in CG, the opposite happened, slow speed presented significant larger magnitudes. In backpacker's group (BpG), the same seems to happen,  $PkVt_{F\_Abs}$ ,  $PkVt_{F\_Norm}$ ,  $PkVt_{S\_Abs}$ ,  $PkVt_{S\_Norm}$ ,  $PkAP_{B\_Abs}$ ,  $PkAP_{B\_Norm}$ ,  $PkAP_{P\_Abs}$  and  $PkAP_{P\_Norm}$  also presented significant larger magnitudes for fast than slow speed. And,  $Vt_{Min\_Abs}$  and  $Vt_{Min\_Norm}$  presented significant larger magnitudes for slow speed.

**Table 2.1. Negative and positive rankings between slow and fast speed in control group and backpacker's group for force variables.**

Variables  <i>Force</i>	CONTROL GROUP			BACKPACKER'S GROUP		
	Negative Rank (mean rank)	Positive Rank (mean rank)	<i>p</i>	Negative Rank (mean rank)	Positive Rank (mean rank)	<i>p</i>
$PkVt_{F\_Abs}$ ( <i>N</i> )	6 (8.33)	54 (32.96)	<0.001	16 (14.50)	44 (36.32)	<0.001
$PkVt_{F\_Norm}$ ( <i>N/BW</i> )	6 (8.83)	54 (32.91)	<0.001	16 (14.38)	44 (36.36)	<0.001
$Vt_{Min\_Abs}$ ( <i>N</i> )	60 (30.50)	0 (0.00)	<0.001	60 (30.50)	0 (0.00)	<0.001
$Vt_{Min\_Norm}$ ( <i>N/BW</i> )	60 (30.50)	0 (0.00)	<0.001	60 (30.50)	0 (0.00)	<0.001
$PkVt_{S\_Abs}$ ( <i>N</i> )	3 (2.33)	57 (31.98)	<0.001	6 (18.33)	54 (31.85)	<0.001
$PkVt_{S\_Norm}$ ( <i>N/BW</i> )	3 (2.33)	55 (30.98)	<0.001	4 (9.50)	54 (30.98)	<0.001
$PkAP_{B\_Abs}$ ( <i>N</i> )	60 (30.50)	0 (0.00)	<0.001	58 (30.48)	1 (2.00)	<0.001
$PkAP_{B\_Norm}$ ( <i>N/BW</i> )	60 (30.50)	0 (0.00)	<0.001	59 (30.98)	1 (2.00)	<0.001
$PkAP_{P\_Abs}$ ( <i>N</i> )	0 (0.00)	60 (30.50)	<0.001	0 (0.00)	60 (30.50)	<0.001
$PkAP_{P\_Norm}$ ( <i>N/BW</i> )	0 (0.00)	60 (30.50)	<0.001	0 (0.00)	60 (30.50)	<0.001

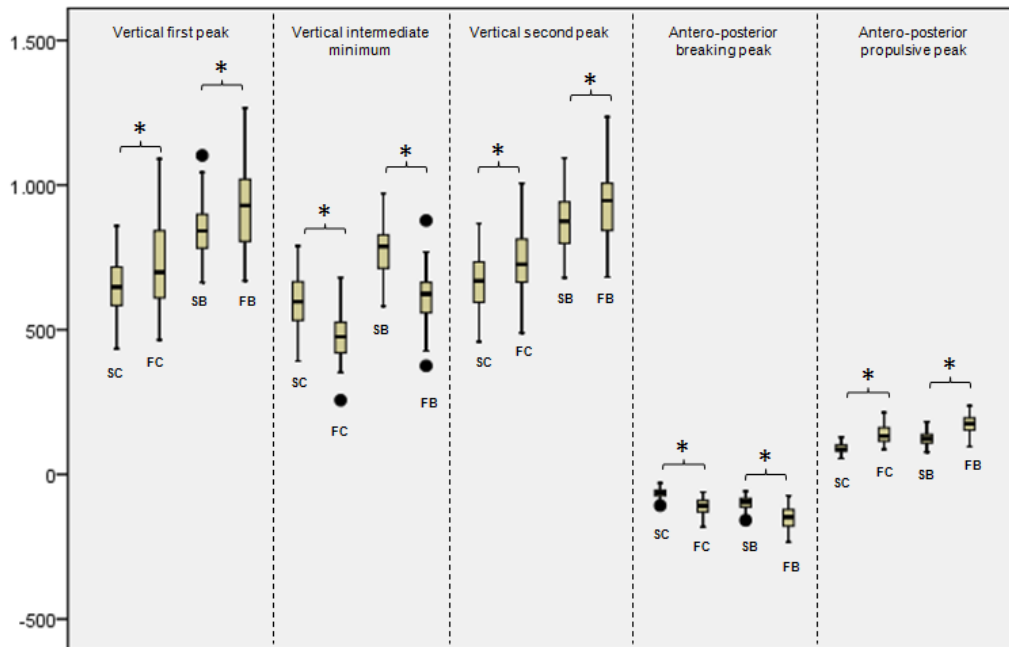
**Negative rank means that slow speed presented higher values than fast speed; positive rank means that fast speed presented higher values than slow speed; significant differences with  $p < 0.05$ .**

Table 2.2 shows, that some variables presented the same median in CG and in BpG at fast speed ( $PkVt_F$ ,  $Vt_{Min}$ ,  $PkAP_P$ ) and at slow speed ( $Vt_{Min}$ ,  $PkVt_S$ ). Besides that, it seems that both

groups, CG and BpG, present a similar behavior when walking speed increase –  $PkVt_F$ ,  $PkVt_S$ ,  $PkAP_B$  and  $PkAP_P$  increased, while  $Vt_{Min}$  decreased.

**Table 2.2. Median and interquartile range for force variables (normalized values).**

Variables	speed	CONTROL GROUP		BACKPACKER'S GROUP	
		Median	Interquartile range	Median	Interquartile range
$PkVt_F$ (N/BW)	Slow	1.00	0.04	0.99	0.05
	Fast	1.08	0.13	1.08	0.14
$Vt_{Min}$ (N/BW)	Slow	0.92	0.02	0.92	0.03
	Fast	0.74	0.12	0.74	0.12
$PkVt_S$ (N/BW)	Slow	1.03	0.03	1.03	0.04
	Fast	1.15	0.11	1.12	0.08
$PkAP_B$ (N/BW)	Slow	-0.10	0.02	-0.11	0.04
	Fast	-0.17	0.06	-0.18	0.06
$PkAP_P$ (N/BW)	Slow	0.14	0.03	0.15	0.04
	Fast	0.21	0.05	0.21	0.04



**Figure 2.1. Median and interquartile range for force variables (absolute values). SC-slow speed in control group; FC-fast speed in control group; SB-slow speed in backpacker's group; FB-fast speed in backpacker's group; \* significant differences with  $p > 0.05$**

Figure 2.1 presents median and interquartile range of the absolute values for all force variables. In both groups – CG and BpG – there seems to be a similar behavior, where both present similar trend and significant differences when changing speed from slow to fast. Once again, we can observe that  $PkV_{tF}$ ,  $PkV_{tS}$ ,  $PkAP_B$  and  $PkAP_P$  increased, in magnitude, by changing speed from slow to fast. The opposite occur to vertical intermediate minimum.

**Table 2.3. Negative and positive rankings between slow and fast speed in control group and backpacker's group for pressure variables.**

Variables  <i>Pressure</i>	CONTROL GROUP			BACKPACKER'S GROUP		
	Negative Rank (mean rank)	Positive Rank (mean rank)	<i>p</i>	Negative Rank (mean rank)	Positive Rank (mean rank)	<i>p</i>
$PkHlx_{Abs}$ (KPa)	14 (19.14)	43 (32.21)	<0.001	20 (17.93)	39 (36.19)	<0.001
$PkHlx_{Norm}$ (%TW/cm <sup>2</sup> )	8 (14.31)	36 (24.32)	<0.001	8 (20.69)	37 (23.50)	<0.001
$PkToes_{Abs}$ (KPa)	17 (17.85)	35 (30.70)	<0.001	13 (12.31)	36 (29.58)	<0.001
$PkToes_{Norm}$ (%TW/cm <sup>2</sup> )	6 (9.50)	21 (15.29)	0.001	7 (14.50)	25 (17.06)	0.001
$PkFF_{Med_{Abs}}$ (KPa)	18 (28.78)	32 (23.66)	0.249	22 (22.95)	27 (26.67)	0.285
$PkFF_{Med_{Norm}}$ (%TW/cm <sup>2</sup> )	15 (20.30)	24 (19.81)	0.224	15 (19.07)	25 (21.36)	0.088
$PkFF_{Ct_{Abs}}$ (KPa)	3 (14.33)	51 (28.27)	<0.001	5 (18.60)	49 (28.41)	<0.001
$PkFF_{Ct_{Norm}}$ (%TW/cm <sup>2</sup> )	5 (15.60)	39 (23.38)	<0.001	10 (16.85)	32 (22.95)	<0.001
$PkFF_{Lat_{Abs}}$ (KPa)	11 (21.45)	39 (26.64)	<0.001	15 (16.27)	33 (28.24)	<0.001
$PkFF_{Lat_{Norm}}$ (%TW/cm <sup>2</sup> )	12 (16.92)	32 (24.59)	0.001	13 (18.50)	24 (19.27)	0.084
$PkMF_{Med_{Abs}}$ (KPa)	24 (24.10)	18 (18.03)	0.112	28 (27.52)	22 (22.93)	0.199
$PkMF_{Med_{Norm}}$ (%TW/cm <sup>2</sup> )	7 (8.00)	7 (7.00)	0.808	11 (8.05)	3 (5.50)	0.018
$PkMF_{Lat_{Abs}}$ (KPa)	29 (25.64)	20 (24.08)	0.193	30 (26.32)	19 (22.92)	0.078
$PkMF_{Lat_{Norm}}$ (%TW/cm <sup>2</sup> )	14 (14.36)	12 (12.50)	0.473	15 (12.83)	9 (11.94)	0.201
$PkRF_{Med_{Abs}}$ (KPa)	6 (19.92)	47 (27.90)	<0.001	8 (18.25)	49 (30.76)	<0.001
$PkRF_{Med_{Norm}}$ (%TW/cm <sup>2</sup> )	4 (22.00)	35 (19.77)	<0.001	4 (20.75)	39 (22.13)	<0.001
$PkRF_{Ct_{Abs}}$ (KPa)	6 (25.42)	49 (28.32)	<0.001	5 (7.00)	51 (30.61)	<0.001
$PkRF_{Ct_{Norm}}$ (%TW/cm <sup>2</sup> )	6 (17.92)	31 (19.21)	<0.001	6 (25.00)	44 (25.57)	<0.001
$PkRF_{Lat_{Abs}}$ (KPa)	19 (26.24)	32 (25.86)	0.123	14 (21.25)	33 (25.17)	0.005
$PkRF_{Lat_{Norm}}$ (%TW/cm <sup>2</sup> )	11 (14.55)	18 (15.28)	0.185	12 (17.38)	22 (17.57)	0.109

**SP-stance phase; negative rank means that slow speed present higher values than fast speed; positive rank means that fast speed present higher values than slow speed; significant differences with  $p < 0.05$ .**

Table 2.3 presents the results for statistical analysis of negative and positive rankings between fast and slow speed either in control group either in backpacker's group for pressure variables.

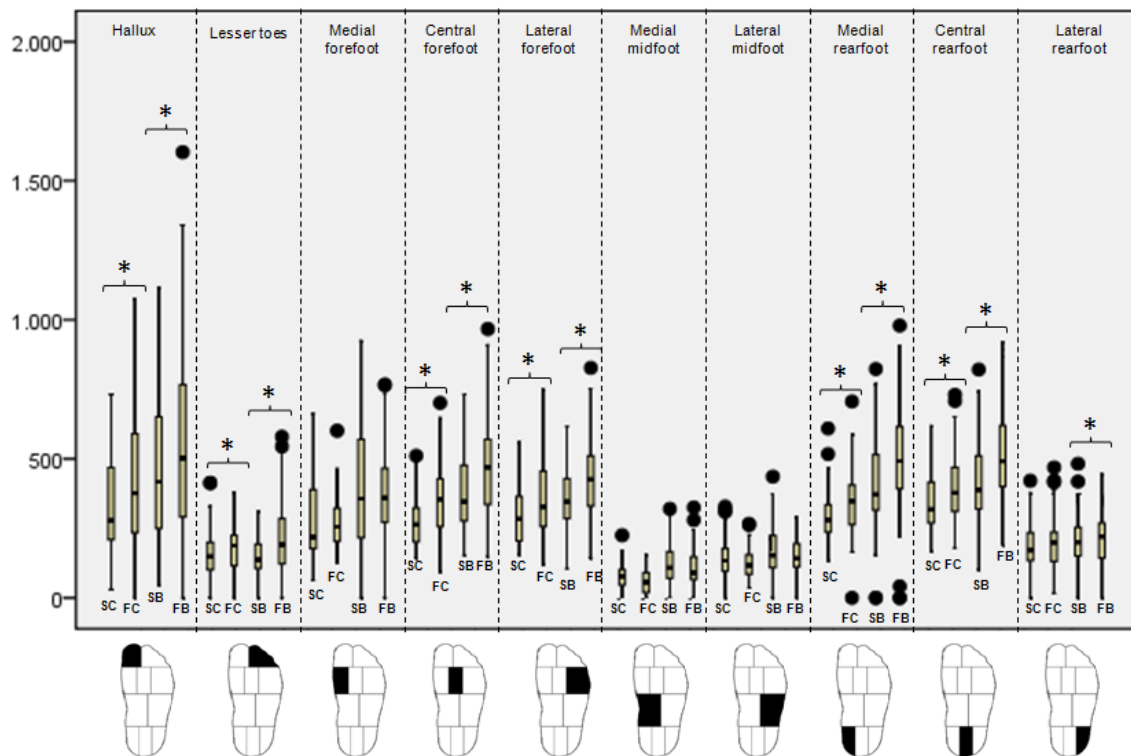
**Table 2.4. Median and interquartile range for pressure variables (normalized values).**

Variables	speed	CONTROL GROUP		BACKPACKER'S GROUP	
		Median	Interquartile range	Median	Interquartile range
PkHlx (%TW/cm <sup>2</sup> )	Slow	3.50	4.00	4.00	5.00
	Fast	5.00	5.00	5.00	6.00
PkToes (%TW/cm <sup>2</sup> )	Slow	1.50	1.00	1.00	1.00
	Fast	2.00	2.00	2.00	2.00
PkFF_Med (%TW/cm <sup>2</sup> )	Slow	3.00	3.00	4.00	3.00
	Fast	4.00	2.25	4.00	3.00
PkFF_Ct (%TW/cm <sup>2</sup> )	Slow	3.00	3.00	4.00	2.00
	Fast	4.00	3.00	5.00	3.00
PkFF_Lat (%TW/cm <sup>2</sup> )	Slow	4.00	2.00	4.00	2.00
	Fast	5.00	4.00	4.00	3.00
PkMF_Med (%TW/cm <sup>2</sup> )	Slow	1.00	1.00	1.00	2.00
	Fast	0.50	1.00	1.00	1.00
PkMF_Lat (%TW/cm <sup>2</sup> )	Slow	1.00	1.00	1.00	2.00
	Fast	1.00	1.00	1.00	1.00
PkRF_Med (%TW/cm <sup>2</sup> )	Slow	4.00	3.00	4.00	2.00
	Fast	5.00	3.00	5.00	2.00
PkRF_Ct (%TW/cm <sup>2</sup> )	Slow	4.00	3.00	4.00	2.00
	Fast	5.00	2.00	6.00	3.00
PkRF_Lat (%TW/cm <sup>2</sup> )	Slow	2.00	2.00	2.00	2.00
	Fast	2.00	2.00	2.00	2.75

As it can be observed in Table 2.3, PkFF<sub>Med\_Abs</sub>, PkFF<sub>Med\_Norm</sub>, PkMF<sub>Med\_Abs</sub>, PkMF<sub>Med\_Norm</sub>, PkMF<sub>Lat\_Abs</sub>, PkMF<sub>Lat\_Norm</sub>, PkMF<sub>Lat\_Time</sub>, PkRF<sub>Lat\_Abs</sub> and PkRF<sub>Lat\_Norm</sub> did not show significant differences between fast and slow speed in CG. CG presented significant higher values for fast than slow speed on PkHlx<sub>Abs</sub>, PkHlx<sub>Norm</sub>, PkHlx<sub>Time</sub>, PkToes<sub>Abs</sub>, PkToes<sub>Norm</sub>, PkToes<sub>Time</sub>,

$PkFF_{Med\_Time}$ ,  $PkFF_{Ct\_Abs}$ ,  $PkFF_{Ct\_Norm}$ ,  $PkFF_{Ct\_Time}$ ,  $PkFF_{Lat\_Abs}$ ,  $PkFF_{Lat\_Norm}$ ,  $PkFF_{Lat\_Time}$ ,  
 $PkRF_{Med\_Abs}$ ,  $PkRF_{Med\_Norm}$ ,  $PkRF_{Ct\_Abs}$  and  $PkRF_{Ct\_Norm}$  variables. For  $PkMF_{Med\_Time}$ ,  
 $PkRF_{Med\_Time}$ ,  $PkRF_{Ct\_Time}$  and  $PkRF_{Lat\_Time}$  slow speed presented significant higher values than  
fast speed in CG. A similar behavior can be observed in BpG. In this group,  $PkHlx\_Time$ ,  
 $PkToes\_Time$ ,  $PkFF_{Med\_Abs}$ ,  $PkFF_{Med\_Norm}$ ,  $PkFF_{Ct\_Time}$ ,  $PkFF_{Lat\_Norm}$ ,  $PkFF_{Lat\_Time}$ ,  $PkMF_{Med\_Abs}$ ,  
 $PkMF_{Lat\_Abs}$ ,  $PkMF_{Lat\_Norm}$ ,  $PkMF_{Lat\_Time}$  and  $PkRF_{Lat\_Norm}$  did not present significant differences  
between slow and fast speed. Fast speed had significant higher values than slow for  $PkHlx\_Abs$ ,  
 $PkHlx\_Norm$ ,  $PkToes\_Abs$ ,  $PkToes\_Norm$ ,  $PkFF_{Med\_Time}$ ,  $PkFF_{Ct\_Abs}$ ,  $PkFF_{Ct\_Norm}$ ,  $PkFF_{Lat\_Abs}$ ,  
 $PkRF_{Med\_Abs}$ ,  $PkRF_{Med\_Norm}$ ,  $PkRF_{Ct\_Abs}$ ,  $PkRF_{Ct\_Norm}$  and  $PkRF_{Lat\_Abs}$  variables. BpG presented  
significant higher values for slow speed at  $PkMF_{Med\_Norm}$ ,  $PkMF_{Med\_Time}$ ,  $PkRF_{Med\_Time}$ ,  $PkRF_{Ct\_Time}$   
and  $PkRF_{Lat\_Time}$ .

From Table 2.4, it can be seen that, when normalizing pressure variables, both groups  
presented an increase of median pressure only for  $PkHlx$ ,  $PkToes$ ,  $PkFF_{Ct}$ ,  $PkRF_{Med}$  and  
 $PkRF_{Ct}$ .  $PkRF_{Lat}$ ,  $PkMF_{Lat}$  did not presented median changes when walking speed increased, for  
both conditions. In CG,  $PkMF_{Med}$  median decreased as speed increased.  $PkFF_{Med}$  and  $PkFF_{Lat}$   
showed an increase of their values when walking speed increases, in CG, and did not showed  
median differences between fast and slow speed.



**Figure 2.2. Median and interquartile range for pressure variables (absolute values). SC-slow speed in control group; FC-fast speed in control group; SB-slow speed in backpacker's group; FB-fast speed in backpacker's group; \* significant differences with  $p > 0.05$**

Figure 2.2 presents median and interquartile range for absolute values of pressure variables. It is noted an increase of absolute peak pressure in most part of plantar pressure regions in both load conditions as speed changes from slow to fast. Apart medial forefoot and midfoot (medial and lateral) in control and backpacker's group and lateral rearfoot in control group, all the others pressure variables presented significant increase of plantar pressure as speed increases.

**Table 2.5. Median and interquartile range of temporal parameters variables.**

Variables	speed	CONTROL GROUP			BACKPACKER'S GROUP		
		Media n	Interquartile range	<i>p</i>	Media n	Interquartile range	<i>p</i>
Duration of stance phase (s)	<i>Slow</i>	1.08	0.11		1.10	0.09	
	<i>Fast</i>	0.68	0.04	<0.001	0.70	0.04	<0.001
Initial double support stance (% SP)	<i>Slow</i>	23.50	10.75		28.00	9.00	
	<i>Fast</i>	23.00	5.00	0.279	24.00	4.75	<0.001
Final double support stance (% SP)	<i>Slow</i>	27.00	11.75		27.00	10.00	
	<i>Fast</i>	22.00	4.25	<0.001	25.00	5.00	0.149
Pkv <sub>F_Time</sub> (% SP)	<i>Slow</i>	27,30	3,40		29,90	3,52	
	<i>Fast</i>	24,82	2,94	<0.001	24,68	2,76	<0.001
Vt <sub>Min_Time</sub> (% SP)	<i>Slow</i>	38,95	9,71		42,65	6,73	
	<i>Fast</i>	47,05	5,40	<0.001	47,50	6,04	<0.001
Pkv <sub>ts_Time</sub> (% SP)	<i>Slow</i>	71,17	2,27		69,58	4,82	
	<i>Fast</i>	76,43	2,55	<0.001	75,24	3,34	<0.001
PkAP <sub>B_Time</sub> (% SP)	<i>Slow</i>	17,62	4,87		16,33	3,15	
	<i>Fast</i>	17,97	3,64	0.166	18,24	2,23	<0.001
PkAP <sub>P_Time</sub> (% SP)	<i>Slow</i>	80,40	2,08		80,09	2,37	
	<i>Fast</i>	84,02	2,12	<0.001	83,64	2,30	<0.001
PKH <sub>x_Time</sub> (%SP)	<i>Slow</i>	79,00	9,00		80,00	11,00	
	<i>Fast</i>	82,00	4,00	0.007	82,00	4,00	0.392
PkToes <sub>Time</sub> (%SP)	<i>Slow</i>	80,00	10,50		83,00	9,00	
	<i>Fast</i>	83,00	3,00	0.034	82,50	6,25	0.540

(to be continued)

**Table 2.5. Median and interquartile range of temporal parameters variables (continuation).**

Variables	speed	CONTROL GROUP			BACKPACKER'S GROUP		
		Media n	Interquartile range	<i>p</i>	Media n	Interquartile range	<i>p</i>
PkFF <sub>Med_Time</sub> (%SP)	Slow	70,00	13,50	<0.001	71,00	14,25	0.043
	Fast	76,50	5,00		74,00	8,00	
PkFF <sub>Ct_Time</sub> (%SP)	Slow	71,00	14,00	0.002	73,00	12,00	0.069
	Fast	76,50	5,00		75,00	5,00	
PkFF <sub>Lat_Time</sub> (%SP)	Slow	70,50	16,00	0.006	74,00	10,00	0.759
	Fast	76,00	6,00		74,00	8,00	
PkMF <sub>Med_Time</sub> (%SP)	Slow	41,50	30,25	0.005	46,00	20,00	0.034
	Fast	32,50	33,50		41,00	27,75	
PkMF <sub>Lat_Time</sub> (%SP)	Slow	48,00	23,00	0.697	51,00	29,00	0.285
	Fast	47,00	20,75		47,00	19,50	
PkRF <sub>Med_Time</sub> (%SP)	Slow	24,00	11,75	0.017	26,00	11,00	<0.001
	Fast	21,00	5,00		21,00	5,00	
PkRF <sub>Ct_Time</sub> (%SP)	Slow	23,50	10,00	0.001	26,00	11,00	<0.001
	Fast	19,00	3,00		20,00	5,00	
PkRF <sub>Lat_Time</sub> (%SP)	Slow	26,00	12,50	0.008	29,00	15,00	0.001
	Fast	22,00	4,00		19,00	8,00	

**SP-stance phase; significant differences with  $p < 0.05$ .**

Table 2.5 presents the results for statistical analysis of median and interquartile range at slow and fast speeds for temporal parameters on CG and BpG. It can be observed that the duration of stance phase at slow speed is significant greater than fast speed in both conditions – CG and BpG. CG did not presented significant values between fast and slow speed to initial double support stance, but presented significant higher values at slow speed than fast speed for final double support stance. On BpG the opposite happened, initial double support stance presented significantly higher values at slow than fast speed, and no significant differences were found at final double support stance.

As to time to GRF events, PkAP<sub>B\_Time</sub> in CG, was the only variable that did not present significant differences between fast and slow speed. Vt<sub>Min\_Time</sub>, PkVt<sub>S\_Time</sub> and PkAP<sub>P\_Time</sub>

presented a significant increase from slow to fast speed, while shows a decrease. In BpG, the same seems to happen,  $V_{t_{\text{Min\_Time}}}$ ,  $PkV_{t_{\text{S\_Time}}}$  and  $PkAP_{\text{P\_Time}}$  also presented a significant increase from slow to fast speed, as well as  $PkAP_{\text{B\_Time}}$ .  $PkV_{t_{\text{F\_Time}}}$  significantly decreased as speed increased.

In the CG,  $PkMF_{\text{Lat\_Time}}$  did not show significant differences between fast and slow speed, however  $PkHlx_{\text{Time}}$ ,  $PkToes_{\text{Time}}$ ,  $PkFF_{\text{Med\_Time}}$ ,  $PkFF_{\text{Ct\_Time}}$  and  $PkFF_{\text{Lat\_Time}}$  variables presented significant higher values for fast than slow speed. For  $PkMF_{\text{Med\_Time}}$ ,  $PkRF_{\text{Med\_Time}}$ ,  $PkRF_{\text{Ct\_Time}}$  and  $PkRF_{\text{Lat\_Time}}$  slow speed presented significant higher values than fast speed, also in CG. A similar behavior can be observed in BpG. In this group,  $PkHlx_{\text{Time}}$ ,  $PkToes_{\text{Time}}$ ,  $PkFF_{\text{Ct\_Time}}$ ,  $PkFF_{\text{Lat\_Time}}$  and  $PkMF_{\text{Lat\_Time}}$  did not present significant differences between slow and fast speed. Fast speed had significant higher values than slow for  $PkFF_{\text{Med\_Time}}$ . BpG presented significant higher values for slow speed at  $PkMF_{\text{Med\_Time}}$ ,  $PkRF_{\text{Med\_Time}}$ ,  $PkRF_{\text{Ct\_Time}}$  and  $PkRF_{\text{Lat\_Time}}$ .

## 4. Discussion

The aim of this study was to verify if dynamometric gait parameters, such GRF and plantar pressure, were affected by speed in the same way when subjects were submitted, or not, to an occasional overload (backpack). Therefore we used absolute and normalized variables for analysis. Absolute variables gives an idea of the total amplitude of differences (load acting in the body), while normalized variables provide us information about the gait pattern.

### 4.1. Force

When analyzing absolute magnitudes of vertical GRF and anterior-posterior GRF, as it was expected, there was an increase of  $PkV_{t_{\text{F}}}$ ,  $PkAP_{\text{B}}$ ,  $PkV_{t_{\text{S}}}$ , and  $PkAP_{\text{P}}$ , as well as a decrease of  $V_{t_{\text{Min}}}$  for both conditions (CG and BpG). This effect may be explained through the increased acceleration (inertial) forces during fast gait. The first ones ( $PkV_{t_{\text{F}}}$  and  $PkAP_{\text{B}}$ ) are related with the breaking phase and heel strike, where the characteristic fast locomotion and segmental speeds requires higher inertial forces to negatively accelerate body and backpack masses. While the second ones ( $PkV_{t_{\text{S}}}$  and  $PkAP_{\text{P}}$ ) correspond to toe-off and propulsion phase, requiring a more intense force to keep this high speed. This phenomena (higher forces during fast gait) was also observed by other authors who investigated the influence of speed in normal (unloaded) gait (Chiu and Wang, 2007; Jordan et al., 2007; Kimberlee et al., 2007; Michael et al., 2008; Orendurff et al., 2008; Xu et al., 2009; Meng-Jung and Mao-Jiun, 2010). When we analyzed the influence of the speed during occasional overload gait by means of the normalized values of vertical GRF and anterior-posterior GRF, we observed the same behavior than for absolute values when we have compared both speeds, suggesting that increasing carried load

did not change the behavior (pattern) of this variables. Therefore as walking speed increases, it seems that there is no change in GRF's gait pattern when walking with an occasional overload when compared to without any extra overload at all.

## 4.2. Pressure

Our results showed, when walking speed increases, a significant increase of the absolute pressure values at *hallux*, lesser toes, central and lateral forefoot and at medial and central rearfoot, for both conditions. It was expected that absolute values present higher values at *hallux*, lesser toe, central forefoot and heel, and did not present significant changes at midfoot when walking speed increased (Gordon et al., 2004; Judith et al., 2004; Segal et al., 2004). Here we found that lateral rearfoot did not present significant different values when increasing walking speed for both conditions (GC and BpG), while medial and central rearfoot did. This fact may have occurred due to heel strike pronation. Normalized values tend to present a similar behavior compared to absolutes ones as speed increases. Nevertheless not all presented significant differences – only PkHlx, PkToes, PkFF<sub>Ct</sub>, PkRF<sub>Med</sub> and PkRF<sub>Ct</sub> presented –, i.e. it seems that the gait pattern did not remain the same when walking carrying an occasional overload compared with the unloaded situation.

## 4.3. Temporal parameters

As it was expected, stance phase was significantly shorter as speed increased (Michael et al., 2008; Stoquart et al., 2008). We have found that the double support phase is shorter during fast gait too, possibly because during slow gait there is a higher medial-lateral shift of the center of pressure and, therefore, a higher instability, being this behavior an adaptation for increased instability during slow gait. Our study also shows that CG and BpG have a similar difference between fast and slow speed in stance phase duration suggesting that occasional overload did not influence stance phase pattern.

The heel strike event occurs earlier as speed increased – PkVt<sub>F\_Time</sub>, PkRF<sub>Med\_Time</sub>, PkRF<sub>Ct\_Time</sub> and PkRF<sub>Lat\_Time</sub>. Single support event – Vt<sub>Min\_Time</sub>, PkMF<sub>Med\_Time</sub> and PkMF<sub>Lat\_Time</sub> – occurs later as speed increase. Both conditions only presented significant differences between speeds for Vt<sub>Min\_Time</sub>, PkMF<sub>Med\_Time</sub>. Occasional overload condition did not present significant differences between fast and slow speed for toe off event, even though unload conditions showed that toe off event occur latter when increasing walking speed – PkVt<sub>S\_Time</sub>, PkAP<sub>B\_Time</sub>, PkHlx<sub>Time</sub>, PkToes<sub>Time</sub>, PkFF<sub>Med\_Time</sub>, PkFF<sub>Ct\_Time</sub> and PkFF<sub>Lat\_Time</sub>.

Indeed, the differences between fast and slow speed seems to be higher for heel strike and single support events, or not significant for toe off event, when carrying occasional overload, which means that gait pattern is influenced by load carriage as speed increases.

## 5. Conclusions

As walking speed increases, it seems that there is no change in gait pattern, concerning to GRF, when walking with and without occasional overload. Unlike what happens with GRF, at plantar pressure level there is an adaptation to an occasional overload condition that is reflected in a change of the gait pattern when walking speed increases. Besides, some temporal parameters were different too, as seen at initial and final double support, PkHalx\_Time, PkToes\_Time, PkFF<sub>Ct\_Time</sub>, PkFF<sub>Lat\_Time</sub> and PkMF<sub>Lat\_Time</sub>.

Therefore, only a more detailed analysis will be able to indentify this difference, which suggests that the analysis of specific regions of the foot is important for an overall understanding about the behavior of the forces acting on the human body.



# Conclusions



With this work it is possible to conclude that both speed and load carriage have effects on gait biomechanical parameters.

With the systematic review of literature it was possible to observe that almost all biomechanical parameters seems to be influenced by gait speed, and that there is an agreement relative to the most common affected variables – like stride and step frequency, stride and step length, time duration of gait cycle, time duration of stance, time duration of double support phase, peak pressure, maximum force, vertical GRF peak and intermediate minimum, time to vertical GRF peaks and intermediate minimum, anterior-posterior GRF peaks, vertical and anterior-posterior impulses, peaks moments and powers and muscle activity. This knowledge is fundamental to prevent body injuries or damages.

An increase in speed is reflected into a significant increase of peak values of force – vertical and anterior-posterior – and a decrease of intermediate minimum values in the vertical GRF component. This behavior is similar either carrying load or not. Peak pressure tend to increase in all plantar footprints as speed increases. Acting to reduce these increases of force and pressure may be a solution to prevent long or short term injuries or damages.



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