ANALYSIS OF GROUND REACTION FORCE IN GAIT DURING DIFFERENT PHASES OF PREGNANCY

Marta Gimunová[1], Mario Kasović[2], Martin Zvonař[1], Pavel Turčínek[3], Branka Matković[2], Pavel Ventruba[4], Martin Vaváček[1] and Damir Knjaz[2]

[1]Faculty of Sports Studies, Masaryk University, Brno, Czech Republic
[2]Faculty of Kinesiology, University of Zagreb, Croatia
[3]Faculty of Business and Economics, Mendel University in Brno, Czech Republic
[4]Department of Gynecology and Obstetrics, Faculty of Medicine,
Masaryk University and Faculty Hospital Brno, Czech Republic

Original scientific paper
UDC: 616-055.26

Abstract:

During pregnancy there are increased biomechanical demands on women affecting gait parameters. The purpose of this study was to analyze changes in vertical ground reaction force (GRF), normalized by body mass, during advancing phases of pregnancy. Nine pregnant subjects participated in this study at three pregnancy stages. To determine in-shoe pressure distribution Pedar Insole System was used (100 Hz). Analysis was done on 200 steps cycles of treadmill walking at the velocity of 0.83 $m \cdot s^{-1}$. To compare the differences of GRFs in maximal weight acceptance, middle stance and push-off phase and time to reach these forces among three pregnancy stages, repeated-measures ANOVA was performed to obtain partial eta-squared values to measure the effect size (η>.10). To interpret the overall mean differences between the three pregnancy stages Cohen's d was applied (d>.20). Altered gait pattern during advancing phases of pregnancy demonstrated in the current study by a significant decrease in force of maximal weight acceptance and an increase in main time variables of the step is suggested to be a protective mechanism against overloading the contact area of the foot despite the increase in body mass.

Key words: *gait, ground reaction force, pregnancy, treadmill walking*

Introduction

During pregnancy there are increased biomechanical demands on women. The most important factors induced by pregnancy, which affect gait parameters and change mechanical loading and joint kinetics, include weight gain, musculoskeletal changes, control of the center of gravity and hormonal changes (Aguiar, et al., 2015; Ribas & Guirro, 2007; Ribeiro, João, & Sacco, 2013). The total mass gained during pregnancy is approximately 12 kg (Ribas & Guirro, 2007) an it puts more load on the joints of lower extremities. Furthermore, ventral growth of the uterus may cause reduction in functional range of motion of the trunk and, together with the head posteriorization, may cause deepening lordosis of the lumbar spine. These changes may lead to center of gravity relocations, which affects balance and gait (Ribas & Guirro, 2007; Ribeiro, et al., 2013; Gilleard, Crosbie, & Smith, 2002).

Effects of hormonal and physiological changes occur alongside with other symptoms such as increased ligamentous laxity and weakening of muscles, especially in breast and belly area (Aguiar, et al., 2015; Máček & Radvanský 2011). Muscular stabilization of the abdominal, paraspinal and gluteal muscles providing stability and control is influenced by pregnancy (Carpes, Reinehr, & Mota, 2008). High fatigability of lower abdominal muscles has been associated with pelvic girdle pain in pregnant women (Gutke, Östgaard, & Öberg, 2008). More than 50% of pregnant women report hip pain and up to 75% of them complain about back and foot pain (Karadag-Saygi, Unlu-Ozkan, & Basgul, 2010; Ponnapula & Boberg, 2010). Muscle fatigability changes influence the mechanical loading and joint kinetics. Increased lower extremity joint moments and powers were observed in pregnant women placing increased demands on hip abductors, hip extensors and ankle plantar flexor muscles during walking (Foti, Davids, & Bagley, 2000).

Braking and propulsive forces are the elemental parts of gait and they are regularly examined by measuring the ground reaction force (GRF) (Giakas & Baltzopoulos, 1997; Hollman, et al., 2007; White, et al., 1999). During walking, GRF is a summation of forces produced by all body segments (Hollman, et al., 2007). The vertical GRF parameters reflect symmetrical lower extremity foot loading patterns and show no significant differences between right and left limb during non-pathological human gait (Giakas & Baltzopoulos, 1997; White, et al., 1999; Dosla, et al, 2013). Functional differences between the limbs, when one limb is suggested to be more responsible for forward propulsion, while the other provides more support and stability, resulting in a slight asymmetry of one or several gait variables, were reported in previous studies (Sadeghi, et al., 2001; Sadeghi, 2003). A greater asymmetry was found at slower velocities (Goble, Marino, & Potvin, 2003). Increases in magnitude and variability of the peaks of GRF during weight acceptance and push-off phases is assumed to be found in people with unstable locomotion (Giakas & Baltzopoulos, 1997; Hollman, et al., 2007).

Biomechanical and clinical studies commonly use treadmill walking to provide subjects' safety and to maintain experimental control of speed (Savelberg, Vorstenbosch, Kamman, Van De Weijer, & Schambardt 1998). Previous studies showed differences between a treadmill and overground walking making the extrapolation of results from the treadmill to overground walking limited (Savelberg, et al., 1998; van Ingen Schenau, 1980; Strathy, Chao, & Laughman, 1983). Compared to the overground walking the treadmill gait differs in faster cadence, a shorter stride length and displacement patterns of the head, hip and ankle in the saggital plane (Murray, Spurr, Gardner, & Mollinger, 1985). However, treadmill and overground gait are considered to be equivalent from the mechanical point of view (van Ingen Schenau, 1980).

The purpose of this study was to analyze changes in gait patterns in vertical GRF, normalized by body mass, at three pregnancy stages. We hypothesized that a substantial increase in body mass and changes in anthropometry during pregnancy will lead to increases in peaks of GRF during mid-stance and push-off phases when maintaining the same walking speed.

Materials and methods

Participants and period of measurement

Nine pregnant women (30.90±2.56 years of age, body height 171.89±4.89 cm) participated in this study. The inclusion criterion was a low-risk pregnancy, whereas the exclusion criteria included any orthopedic or neurological disorders that could influence the gait. Eight pregnant women were primigravid, one was in her second pregnancy (2.5 years after the first delivery). The average body mass at each collection session and its timing as regards gestation period are shown in Table 1.

Prior to the study, volunteers were informed about the measurement procedure and a written informed consent was obtained from them. The protocol was approved by the local ethical committee of the Faculty of Sports Studies, Masaryk University, Brno, the Czech Republic.

Experimental protocol

Data were collected at the Laboratory of Kinanthropological Research on the campus of Masaryk University of Brno, the Czech Republic. To determine the in-shoe pressure distribution during walking, the Pedar Insole System (Novel GmbH, Munich, Germany) was used. The system measures foot pressure distribution using 99 capacitive sensors, connected to a small portable data acquisition device, which was fastened by a belt on the subjects' waist. Sampling rate was 100 Hz. Three different insole sizes (European size 36-37, 38-39 and 40-41) were used to account for differences in foot size. All subjects were provided with the identical kind of footwear, sport shoes, to control for differences in personal footwear.

During the experiment, subjects were asked to walk for five minutes on a treadmill (Katana Sport 400 V, Lode, Groningen, Netherlands) at the velocity of 0.83 $m \cdot s^{-1}$. It is characteristic for the self-selected gait velocity to be slightly slower with the advancing phases of pregnancy (Forczek & Staszkiewicz, 2012). Decreased walking speed, to 1±0.2 $m \cdot s^{-1}$, was found in the study by Blaszczyk, Opala-Berdzik, and Plewa (2015) during the last trimester of pregnancy. The velocity in the current study was assessed at 0.83 $m \cdot s^{-1}$ to be manageable at all the studied pregnancy stages with the possible pregnancy-related inconveniences during locomotion taking into consideration. Analysis was done on 400 steps performed by either leg selected from the steady data segment of treadmill walking at a desired speed.

Treadmill walking differs from normal walking by artificial pace, inability to change the speed voluntarily and reduced stride variability. Treadmill walking was used to keep the subjects' safety and to maintain experimental control of speed, as the

Table 1. Mean body mass (kg) at each collection session and its timing (gestational weeks)

	First measurement	Second measurement	Third measurement
Gestational week	13.27±3.96	26.35±2.85	36.30±1.40
Mean body mass	67.45±13.27	74.99±13.68	78.30±13.47

foot pressure distribution and force are affected by walking speed and stride variability (Cavanagh, et al., 1997; Hessert, et al. 2005).

Data analysis

For the data processing Microsoft Office Excel 2007 (Microsoft Corporation) was used. A low-pass filter with a cut-off frequency of 50 N was applied. The following variables (Figure 1) were determined by a self-developed algorithm based on tracking the force values during the entire time of each step cycle, thus finding the maximal force values in maximal weight acceptance, mid stance and push-off phases. For further analysis the following variables were selected: *FA* maximal force in maximal weight acceptance (*MWA*); *TA* time to reach MWA; *FB* maximal force in mid stance (*MS*); *TB* time to reach MS; *FC* maximal force in push-off (*PO*); *TC* time to reach PO; *TD* time to reach end of the stance phase; *TS* time of the swing phase; *TE* time to reach end of the step. All force variables were normalized by body mass.

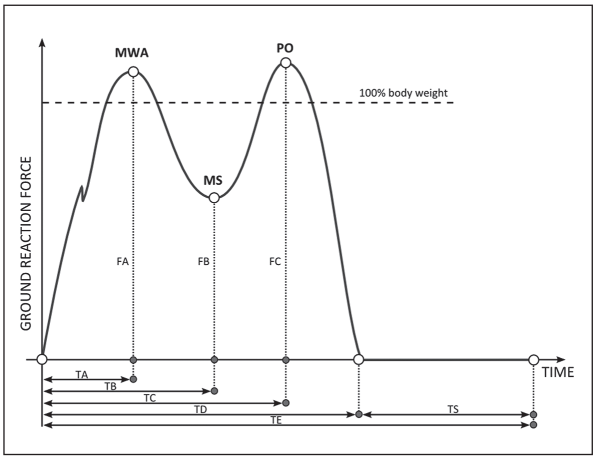

Figure 1. Graph representing ground reaction force during step cycle with the analyzed variables. FA maximal force in maximal weight acceptance (MWA); TA time to reach MWA; FB maximal force in mid stance (MS); TB time to reach MS; FC maximal force in push-off (PO); TC time to reach PO; TD time to reach end of the stance phase; TS time of the swing phase; TE time to reach end of the step. All force variables were normalized by body mass.

Statistical analysis

Means and standard deviations (SD) were calculated for all GRFs, as well as time variables of the first, second and third collection session. Repeated-measures ANOVA was performed to compare the differences among the three pregnancy stages by the effect size obtained by the partial eta-squared values (η>.10). Cohen's d (d>.20) was applied afterwards to interpret the overall mean differences between the three pregnancy stages. All statistical analyses were conducted using Statistica.12 software.

Table 2. Means, standard deviations of force (N·kg^{-1}) and time (s) variables for the left foot

	First measurement	Second measurement	Third measurement
	Mean±SD	Mean±SD	Mean±SD
FA	8.69±0.96	8.36±1.25	8.00±1.20
TA	0.25±0.04	0.27±0.04	0.30±0.05
FB	7.76±0.87	7.55±1.34	7.50±1.37
TB	0.39±0.06	0.40±0.05	0.40±0.05
FC	9.34±1.00	9.21±1.71	9.30±1.72
TC	0.62±0.05	0.63±0.05	0.60±0.06
TD	0.82±0.05	0.83±0.05	0.90±0.04
TS	0.47±0.03	0.47±0.03	0.50±0.04
TE	1.29±0.07	1.30±0.07	1.30±0.07

FA maximal force in maximal weight acceptance (*MWA*); *TA* time to reach MWA; *FB* maximal force in mid stance (*MS*); *TB* time to reach MS; *FC* maximal force in push-off (*PO*); *TC* time to reach PO; *TD* time to reach end of the stance phase; *TS* time of the swing phase; *TE* time to reach end of the step. All force variables were normalized by body mass.

Table 3. Means, standard deviations of force (N·kg^{-1}) and time (s) variables for the right foot

	First measurement	Second measurement	Third measurement
	Mean±SD	Mean±SD	Mean±SD
FA	8.74±1.15	8.44±1.34	8.20±1.36
TA	0.26±0.04	0.27±0.03	0.30±0.05
FB	7.89±1.04	7.71±1.44	7.70±1.65
TB	0.39±0.06	0.40±0.04	0.40±0.06
FC	9.71±1.15	9.58±1.77	9.70±2.01
TC	0.62±0.05	0.64±0.05	0.70±0.04
TD	0.82±0.05	0.83±0.05	0.90±0.05
TS	0.47±0.04	0.46±0.03	0.50±0.04
TE	1.29±0.07	1.30±0.07	1.30±0.07

FA maximal force in maximal weight acceptance (*MWA*); *TA* time to reach MWA; *FB* maximal force in mid stance (*MS*); *TB* time to reach MS; *FC* maximal force in push-off (*PO*); *TC* time to reach PO; *TD* time to reach end of the stance phase; *TS* time of the swing phase; *TE* time by reach end of the step.

Results

The statistical analyses revealed significant differences in GRFs and in time to reach these forces among the three pregnancy stages. Mean and SD of each variable are shown in Table 2 and 3. Table 4 shows partial eta-squared values (95% CI) and values of Cohen's d.

Ground reaction forces

From the 13th to the 26th and to the 36th gestation week the maximal force in MWA significantly decreased (η>.10, d>.20) in both feet. The change in force of the mid stance effect size point estimate was not significant by eta (η<.10), whereas the

Table 4. Force and time variables partial eta-squared values, η>.10 small, >.30 moderate, >.50 large significance (Hopkins, 2000), Cohen's d values, d>.20 small, >.50 moderate, >.80 large significance (Cohen, 1977)

	η	d 1 – 2	d 2 – 3	d 1 – 3
FAL	.18	.30 (–.33 – 1.12)	.31 (–.51 – 1.09)	.66 (.03 – 1.44)
TAL	.18	.50 (.47 – .53)	.25 (.22 – .28)	.75 (.72 – .78)
FBL	.03	.19 (–.38 – 1.07)	.05 (–.82 – .95)	.25 (–.32 – 1.15)
TBL	.25	.12 (.09 – .16)	.18 (.15 –.22)	.06 (.02 – .09)
FCL	.01	.10 (–.54 – 1.21)	.05 (–1.07 – 1.16)	.04 (–. 61 – 1.16)
TCL	.06	.18 (.14 – . 21)	.17 (.13 – .20)	.35 (.31 – .38)
TDL	.21	.20 (.17 – .23)	.44 (.42 – .48)	.67 (.64 – .70)
TSL	.39	.01 (–.01 – .03)	.03 (.01 – .05)	.03 (.00 – .05)
TEL	.17	.14 (.10 – .19)	.29 (.24 – .33)	.43 (.38 – .47)
FAR	.12	.24 (–.51 – 1.12)	.20 (–.68 – 1.09)	.45 (–.30 – 1.34)
TAR	.19	.03 (–.19 – .28)	.11 (.07 – .32)	.67 (.64 –.70)
FBR	.02	.15 (–.53 – 1.09)	.02 (–.92 – 1.10)	.16 (–.52 – 1.24)
TBR	.15	.19 (.16 – .23)	.07 (.04 – .11)	.11 (.07 – .14)
FCR	.00	.09 (–.66 – 1.25)	.04 (–1.28 – 1.19)	.04 (–.71 – 1.35)
TCR	.23	.23 (.20 – .26)	.47 (.44 – .50)	.70 (.68 – .74)
TDR	.31	.20 (.17 – .23)	.40 (.37 –.43)	.60 (.57 –.63)
TSR	.49	.29 (.26 – .31)	.09 (.06 – .11)	.25 (.22 – . 28)
TER	.15	.14 (.10 – .19)	.29 (.24 –.33)	.43 (.38 – .47)

* d 1 – 2 (differences between the first and second collection session), d 2 – 3 (differences between the second and third collection session), d 1 – 3 (differences between the first and third collection session).

FA maximal force in maximal weight acceptance (*MWA*); *TA* time to reach MWA; *FB* maximal force in mid stance (*MS*); *TB* time to reach MS; *FC* maximal force in push-off (*PO*); *TC* time to reach PO; *TD* time to reach end of the stance phase; *TS* time of the swing phase; *TE* time to reach end of the step. All force variables were normalized to body mass.

Cohen's d assessed the significant change in force of mid stance between the 1st and 3rd trimester in the left foot (d>.20). The decrease from the 1st to the 3rd trimester in force of the push-off phase effect size point estimate was not significant (η<.10, d<.20).

Time to reach GRFs

Time to reach first maximum force significantly increased during the advancing phases of pregnancy (η>.10, d>.20). Time to reach force of middle stance significantly increased from the first to the second collection session (η>.10), however Cohen's d was not significant (d<.20). Time to reach force of push-off increased; however the significant substantive difference by eta and Cohen's d was found only for the right foot (η>.10, d>.20). A significant increase was found in time of the stance phase, time of the swing phase and in time of the entire step cycle during advancing phases of pregnancy (η>.10, d>.20).

Discussion and conclusions

The purpose of this study was to analyze changes of gait patterns in vertical GRF caused by advancing pregnancy. Two hundred step cycles of treadmill walking at the velocity of 3 km across three pregnancy stages were analyzed. It was hypothesized that vertical force, normalized by body mass, would be larger alongside pregnancy course. However, the force of maximal weight acceptance, mid stance and push-off phase decreased from the first to the third trimester of pregnancy.

Significant decreases in peaks of GRFs were found in the current study. The shortened peak forces are related to longer contact times. This is suggested to be a protective mechanism the purpose of which is to keep loading unchanged despite the increase in body mass (McCrory, Chambers, Daftary, & Redfern, 2011; Nilsson & Thorstensson, 1989) and, at the same time, it is a physiological reaction to protect the fetus from extensive tremor and shaking. Accumulation of weight gained during the pregnancy in the abdominal region is suggested to be the primary cause of changes in plantar pressure and balance (Karadag-Saygi, et al., 2010).

Similar observations were found in the overweight population. In comparison to adults with normal weight, when normalized by body mass, the decreased vertical GRF peaks were found in overweight population. It seems to be a musculoskeletal system strategy to minimize joint contact forces and shear stress despite the excessive body mass while walking at a self-selected speed. (Castro, et al, 2014)

McCrory and colleagues (2011) reported no differences in vertical GRFs between trimesters when changing walking velocity was considered. Locomotion in pregnant women is characterized by a slower speed, lower frequency and shorter length of steps in comparison to pre- and post-pregnancy states (Forczek & Staszkiewicz, 2012). Longer stance time was observed in the last trimester by Karadag-Saygi et al. (2010) and Forczek and Staszkiewicz (2012), as well as in our study. This prolonged time of the stance phase has been associated with the need to increase safety of the movement during pregnancy (Forczek & Staszkiewicz, 2012; Karadag-Saygi, et al., 2010). To reduce the possibility of changing velocity voluntary, as GRFs are affected by walking speed (Cavanagh, et al. 1997; Hessert, et al., 2005), treadmill walking was used in the current study.

The major limitation of the study was a small number of participants and a difference between treadmill and overground gait, which limits the extrapolation of results. Another limitation was that the anthropometrical parameters (body mass, body height) of participants were not homogenous.

Future studies should be conducted to clarify the differences in the symmetry of foot loading patterns and laterality of pregnant women. This information will allow us to get a deeper insight into the differences in gait patterns during the first, second and third trimester of pregnancy.

Analyses of 200 step cycles demonstrated altered foot loading pattern during pregnancy. As pregnancy advances, force of maximal weight acceptance decreases significantly and values of the analyzed time variables increase (η>.10, d>.20) despite the same walking speed in all the collection sessions assessed by a treadmill. These findings are suggested to be a pregnancy physiological reaction to protect the fetus against extensive tremor and shaking and, at the same time, a protective mechanism against overload of the contact area of the foot pending due to the increase in body mass. Deeper understanding of changes in GRF will explain alterations of the gait pattern in pregnant body and describe the significance of specific footwear and exercise programs to preserve structure of healthy foot during pregnancy.

References

Aguiar, L., Santos-Rocha, R., Vieira, F., Branco, M., Andrade, C., & Veloso, A. (2015). Comparison between overweight due to pregnancy and due to added weight to simulate body mass distribution in pregnancy. *Gait & Posture, 42*(4), 511-517.

Błaszczyk, J.W., Opala-Berdzik, A., & Plewa, M. (2016). Adaptive changes in spatiotemporal gait characteristics in women during pregnancy. *Gait & Posture*, *43*, 160-164.

Carpes, F.P., Reinehr, F.B., & Mota, C.B. (2008). Effect of a program for trunk strenght and stability on pain, low back and pelvis kinematice, and body balance: A pilot study. *Journal of Bodywork and Movement Therapies*, *12*, 22-30.

Castro, M.P., Abreu, S.C., Sousa, H., Machado, L., Santos, R., & Vilas-Boas, J.P. (2014). In-shoe plantar pressure and ground reaction forces during overweight adults‘ overground walking. *Research Quarterly for Exercise and Sport*, *85*, 188-197.

Cavanagh, P.R., Morag, E., Boulton, A.J.M., Young, M.J., Deffner, K.T. & Pammer, S.E. (1997). The relationship of static foot structure to dynamic foot function. *Journal of Biomechanics, 30*, 243-250.

Cohen, J. (1977). *Statistical power analysis for behavioral sciences* (rev. ed.). New York: Academic Press.

Dosla, J., Korvas, P., Zvonar, M., Musil, R., Senkyr, J., & Kalina, T. (2013). Comparison of selected characteristics of gait in men and women. *Journal of Human Sport and Exercise*, *8*(2), 114-119.

Forczek, W., & Staszkiewicz, R. (2012). Changes of kinematic gait parameters due to pregnancy. *Acta of Bioengineering and Biomechanics, 14*, 113-119.

Foti, T., Davids, J.R., & Bagley, A. (2000). A biomechanical analysis of gait during pregnancy. *Journal of Bone and Joint Surgery American Edition, 82*, 625-632.

Giakas, G., & Baltzopoulos, V. (1997). Time and frequency domain analysis of ground reaction forces during walking: An investigation of variability and symmetry. *Gait & Posture, 5*, 189-197.

Gilleard, W., Crosbie, J., & Smith, R. (2002). Effect of pregnancy on trunk range of motion when sitting and standing. *Acta Obstetricia Gynecologica Scandinavica*, *81*, 1011-1020.

Goble, D.J., Marino, G.W., & Potvin, J.R. (2003). The influence of horizontal velocity on interlimb symmetry in normal walking. *Human Movement Science*, *22*, 271-283.

Gutke, A., Östgaard, H.C., & Öberg, B. (2008). Association between muscle function and low back pain in relation to pregnancy. *Journal of Rehabilitation Medicine, 40*, 304-311.

Hessert, M.J., Vyas, M., Leach, J., Hu, K., Lipsitz, L., & Novak, V. (2005). Foot pressure distribution during walking in young and old adults. *BCM Geriatrics, 5*, 1-8.

Hollman, J.H., Brey, R.H., Bang, T.J., & Kaufman, K.R. (2007). Does walking in a virtual enviroment induce unstable gait? An examination of vertical ground reaction forces. *Gait & Posture, 26*, 289-294.

Hopkins, W.G. (2000). *A new view of statistics.* Internet Society for Sport Science. Retrieved April 22, 2015 from: http://www.sportsci.org/resource/stats/.

Karadag-Saygi, E., Unlu-Ozkan, F., & Basgul, A. (2010). Plantar pressure and foot pain in the last trimester of pregnancy. *Foot & Ankle International, 31,* 153-157.

Máček, M., & Radvanský, J. (2011). *Fyziologie a klinické aspekty pohybové aktivity.* [Physiology and clinical aspects of physical activity. In Czech.] Praha: Galén.

McCrory, J.L., Chambers, A.J., Daftary, A., & Redfern, M.S. (2011). Ground reaction forces during gait in pregnant fallers and non-fallers. *Gait & Posture, 34*, 524-528.

Moretto, P., & Bisiaux, M. (2008). The effects of fatigue on plantar pressure distribution in walking. *Gait & Posture, 28*, 693-698.

Murray, M.P., Spurr, G.B., Sepic, S.B., Gardner, G.M., & Mollinger, L.A. (1985). Treadmill versus floor walking: Kinematics, electromyogram, and heart rate. *Journal of Applied Physiology*, *59*, 87-91.

Nilsson, J., & Thorstensson, A. (1989). Ground reaction forces at different speeds of human walking and running. *Acta Physiologica Scandinavica, 136*, 217-227.

Ponnapula, P., & Boberg, J.S. (2010). Lower extremity changes experienced during pregnancy. *Journal of Foot & Ankle Surgery, 49*, 452-458.

Ribas, S.I., & Guirro, E.C.O. (2007). Analysis of plantar pressure and postural balance during different phases of pregnancy. *Brazilian Journal of Physical Therapy, 11*, 391-396.

Ribeiro, A.P., João, S.M., & Sacco, I.C. (2013). Static and dynamic biomechanical adaptations of the lower limbs and gait pattern changes during pregnancy. *Women's Health, 9*, 99-108.

Sadeghi, H. (2003). Local or global asymmetry in gait of people without impairments. *Gait & Posture*, *17*(3), 197-204.

Sadeghi H., Sadeghi, S., Prince, F., Allard, P., Labelle, H., & Vaughan, C.L. (2001). Lower limb muscle power relationships in bilateral able-bodied gait. *American Journal of Physical Medicine and Rehabilitation, 80*(11), 821-830.

Savelberg, H.H.C.M., Vorstenbosch, M.A.T.M., Kamman, E.H., Van De Weijer, J.G.W., & Schambardt, H.C. (1998). Intra-stride belt-speed variation affects treadmill locomotion. *Gait and Posture*, *7*(1), 26-34.

Strathy, G.M., Chao, E.Y., & Laughman, R.K. (1983). Changes in knee function associated with treadmill ambulation. *Journal of Biomechanics*, *16*(7), 517-522.

van Ingen Schenau, G.J. (1980). Some fundamental aspects of the biomechanics of overground versus treadmill locomotion. *Medicine and Science in Sports and Exercise*, *12*(4), 257-261.

Voloshin, A.S., Mizrahi, J., Verbitsky, O., & Isakov, E. (1998). Dynamic loading on the human musculoskeletal system, effect of fatigue. *Clinical Biomechanics, 13*, 515-520.

White, R., Agouris, I., Selbie, R.D., & Kirkpatrick, M. (1999). The variability of force platform data in normal and cerebral palsy gait. *Clinical Biomechanics, 14*, 185-192.

Submitted: July 5, 2015
Accepted: December 3, 2015

Correspondence to:
Marta Gimunová
Master of Anthropology, Lecturer of Anatomy
Faculty of Sports Studies, Masaryk University
Kamenice 5, Brno, Czech Republic, 62500
Phone: +420728367050
E-mail: marta.gimunova@hotmail.com

Acknowledgements

We would like to thank Mrs. Hanzlová for her assistance with the collection of the data and Ms. Willy A. Pieter for language support and constructive recommendations in preparing this manuscript. This research was supported by MH CZ – DRO (FNBr, 65269705).

Conflict of interest statement

The authors confirm that there is no conflict of interest in this submitted work, entitled "Analysis of ground reaction force in gait during different phases of pregnancy ".

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.