



DO MEN AND WOMEN USE SIMILAR ADAPTIVE LOCOMOTION TO CLEAR STATIC AND DYNAMIC OBSTACLES?

doi: 10.2478/v10038-010-0029-8

LILIAN TERESA BUCKEN GOBBI*, JEAN JOSÉ DA SILVA, FABIO AUGUSTO BARBIERI

Posture and Gait Studies Lab., UNESP – São Paulo State University at Rio Claro SP, Brazil

ABSTRACT

Purpose. The purpose of this study was to analyze the influence of gender on the adaptive locomotion in the clearance of obstacles. Specifically, it was evaluated if there are differences in the space-temporal parameters between male and female in the clearance of and dynamic obstacles moving at both slow and fast speeds. **Basic procedures.** Five young male adults and five young female adults took part in this study. The task was performed in three conditions: static obstacle and dynamic obstacle – clearance perpendicular to the participant's trajectory at slow speed (1.07 m/s) and at fast speed (1.71 m/s). The trials were recorded by two digital cameras and spatial-temporal information was obtained. **Main findings.** The dynamic obstacle conditions required more visual inspection. The results showed different adaptive locomotion between the sexes. The distinct gait patterns were evidenced for the spatial and temporal variables and cadence in the three conditions. **Conclusions.** The women presented a more conservative behavior, which was evidenced by the increase of the length in the penultimate step and in the toe clearance.

Key words: adaptive locomotion, dynamic obstacle, gender

Introduction

The difference between the sexes is extensively discussed in the literature. Men and women show differences in the anthropometric and constitutional characteristics [1–3], neuromuscular characteristics [4–6] and in physical capacities [7–8], among others. As for the gait, a comparison between the sexes has pointed to the similarity in the gait speed and differences in the step length (shorter for women), cadence (faster for men) and movement patterns [1, 3, 9, 10]. However, it has not been clarified how men and women program and execute locomotor adaptations in the clearance, especially the transposition of dynamic obstacles.

Adaptive locomotion is understood as the ability to adjust the basic locomotion pattern according to the environmental features, considering the individual's conditions and the task's objective, aiming to maintain the dynamic balance. Adaptive locomotion strategies are indicated by alterations in the base of support amplitude adopted to maintain balance, in the proper adjustment to the feet positioning before the clearance and in the safety margin over the obstacle [11]. The programming of strategies in the obstacle transposition takes into consideration the characteristics of the obstacle [12–15].

Obstacle speed affects the locomotor behavior and strategies were distinct in the obstacle avoidance phases [16]. Accordingly, the current study aims at clarifying the following questions: Are the adaptive locomotor strategies used by men and women different? Which spatial-temporal parameters are important to explain the strategies used? Are the strategies used the same for static and dynamic obstacles?

The aim of this study was to analyze the influence of sex on the adaptive locomotion in the obstacle avoidance task. Specifically, it was evaluated if there are differences in the spatial-temporal parameters between men and women in negotiating static and dynamic obstacles at slow and fast speeds. The hypothesis in this study is that the strategies used are different between the sexes, once the constitutional, genetic and physical abilities interfere in the gait [1–3, 7].

Material and methods

Participants

Five young male adults and five young female adults took part in this study (Tab. 1). All participants were right footed. They gave their informed consent to the experimental procedure as required by the Declaration of Helsinki and the institutional Research Ethics Committee (Protocol# 004387/2003). The exclusion criteria were the presence of skeletal or neuromuscular damage

* Corresponding author.

Table 1. Participants' characteristics and obstacle height for the groups of men and women

	Age (years)	Body Mass (kg)*	Height (m)*	Lower limb length (m)*	Height of obstacle (m)
Men	23.37 ± 2.13	68.16 ± 8.02	1.74 ± 0.05	0.90 ± 0.04	0.50 ± 0.02
Women	22.40 ± 1.04	60.56 ± 9.94	1.66 ± 0.05	0.87 ± 0.02	0.47 ± 0.03

*statistical difference between sexes ($p < 0.05$)

and/or vision problems not corrected by the use of glasses or lenses.

Task

The task consisted in walking along a corridor (8 m long and 0.5 m wide) and crossing an obstacle (50 cm long and 0.5 cm wide) with the right leg [16] (Fig. 1). The height of the obstacle (Tab. 1) was personalized for each participant corresponding to the knee's height to compensate the anthropometric difference between the groups. The initial comparison between sexes indicated higher values of body mass ($F_{1,48} = 8.85$, $p < 0.05$), height ($F_{1,48} = 26.11$, $p < 0.0001$) and right lower limb length ($F_{1,48} = 11.97$, $p < 0.001$) for the male group (Tab. 1).

Each participant carried out the task in three conditions: (1) static obstacle; (2) clearance perpendicular to the trajectory of the participant at slow speed (1.07 m/s); (3) clearance perpendicular to the trajectory of the participant at fast speed (1.71 m/s). These speeds were established on the basis of the adult unobstructed gait speed (1.33 m/s; deviation of nearly 20%) [17]. Three familiarization trials were made for each condition. Fifteen trials per participant were collected, in blocks of five trials for each condition. The presentation order of the blocks was randomized among the participants.

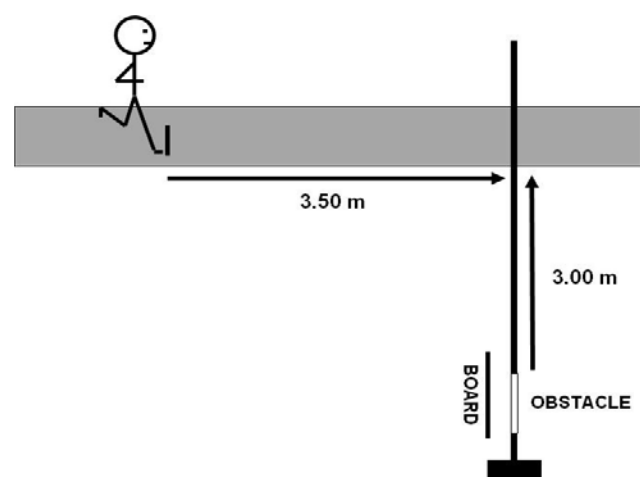


Figure 1. Representation of the experiment

The static obstacle was placed 5 m from the participant's starting point. In the dynamic obstacle task, the obstacle was attached to a cart and conducted along the rails. The cart's control box commanded an engine (WEG, model 71, 0.33 cv, tri-phase; 1.6 A, 60 HZ; 220 v; 1720 RPM) with a frequency inverter (TOSHIBA, model VF-SX, 220v, 0.75 kW) whose panel registered the rotation of the engine [16]. The key to direct the obstacle motions was attached to the inverter. The obstacle motion started when the participant crossed a mark 3.5 m distant from the rail. To eliminate the perception of the obstacle acceleration, a screen (1 m × 0.80 m) was placed at the beginning of the obstacle's trajectory.

Procedures

Reflective markers (of 15 mm diameters) were attached to the distal phalanx of the fifth metatarsal and lateral side of right and left calcaneus. A marker was also attached to the superior edge of the obstacle. The trials of the participants were recorded by two digital cameras (JVC – model GR-DVL 9800) with shutter speed of 1/250 and frequency collection of 60 Hz. The cameras were placed at an angle of 90° between them in order to record all of the markers and right-sided strides. The images were analyzed by DVIDEO software [18]. The Direct Linear Transformation (DLT) method [19] was used to obtain the tridimensional coordinates of each marker. The calibration of the collection place was made by a volumetric object (1.5 × 1 × 4 m) of known measurements. The applied reference system was oriented along z axis in vertical direction (upwards); y axis with direction and orientation of the participant's gait (orthogonal to z) and x axis with direction and orientation defined by the vector product of y and z . The experimental error was measured by accuracy test [16, 20] and the calculated error value was 16 mm.

Dependent variables

Ten dependent variables were used to describe the subjects' locomotor behavior. The spatial and temporal variables analyzed in this study were: last step length

(N-1) and penultimate step (N-2) length (horizontal distance between the right and left heels' markers in the last and penultimate steps before the obstacle approach); take-off and landing distance (horizontal distance at the moment when the marker of the fifth metatarsus of the leading limb loses contact with the ground before and after the clearance); toe clearance (vertical distance between the marker of the fifth metatarsus of the leading limb and the top of the obstacle at the moment when the foot is over it); N-1 and N-2 duration (time between the contacts of right and left heels in the last and penultimate steps); clearance duration (time in which the right foot loses contact with the ground before the obstacle until the next contact after the obstacle); cadence (number of steps per minute); and average gait speed (distance which was covered in the last step divided by its duration). Distance parameters (N-1, N-2, take-off and landing distance, toe clearance, cadence and average gait speed) were normalized by the subject's body weight [21].

Statistic analysis

Data was filtered by the 4th order Butterworth digital filter under a cut frequency of 5 Hz through MATLAB 6.5[©] software. The Shapiro-Wilk test showed that the distributions used for the analysis did not depart from the norm ($p > 0.05$). Three multivariate analyses of variance were carried out – MANOVA – (2X3), i.e. two genders and three conditions (obstacle at fast and slow speeds and static position) as factors. The condition factor was treated as repeated measurements. The first MANOVA analyzed the spatial variables (N-1; N-2; take-off distance; landing distance; and toe clearance). The second one analyzed the temporal variables (N-1 and N-2 duration; and clearance duration) and the third one analyzed the cadence and the average gait speed variables. When the MANOVA pointed out significant difference, Tukey univariate tests were carried out, as proposed by Zar [22]. In all the statistics analysis, a significance level of $\alpha < 0.05$ was established. Software SPSS 10.0[©] was used for these analyses.

Results

As for the spatial variables, the MANOVA revealed that the locomotor behavior was affected by sex (Wilks' Lambda = 0.21, $F_{5,39} = 29.04$, $p < 0.0001$) and condition (Wilks' Lambda = 0.08, $F_{10,34} = 37.53$, $p < 0.0001$), without interaction between the factors. The univariate analysis showed bigger N-2 for the three conditions of the study ($F_{1,43} = 31.24$, $p < 0.001$), N-1 ($F_{1,43} = 4.25$,

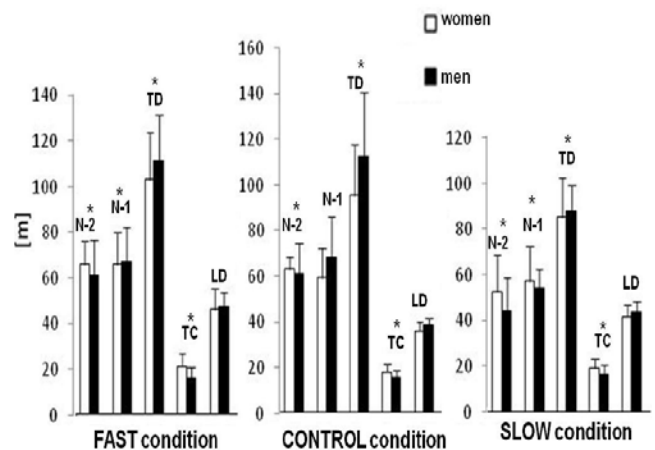


Figure 2. Average and standard deviation of spatial variables for the group of men and women. N-2 = N-2 length; N-1 = N-1 length; TD = take-off distance; TC = toe clearance; LD = landing distance. * statistical difference between sexes ($p < 0.05$)

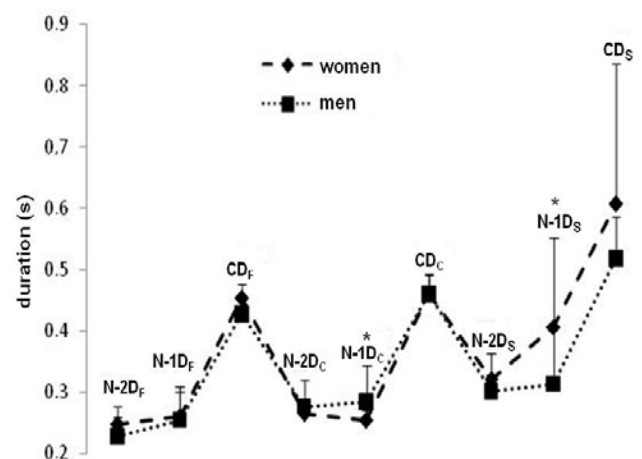


Figure 3. Average and standard deviation in the temporal variables for the groups of men and women. F = obstacle condition in fast speed; C = obstacle condition in stationary position; S = obstacle condition in slow speed; N-2D = N-2 duration; N-1D = N-1 duration; CD = clearance duration. * statistical difference between sexes ($p < 0.05$)

$p < 0.04$) and toe clearance ($F_{1,43} = 17.655$, $p < 0.0001$) for the group of women (Fig. 2).

The temporal variables were also affected by sex (Wilks' Lambda = 0.69, $F_{6,32} = 5.03$, $p < 0.005$) and condition (Wilks' Lambda = 0.19, $F_{6,32} = 22.74$, $p < 0.0001$). An interaction between the factors (Wilks' Lambda = 0.57, $F_{6,32} = 3.95$, $p < 0.005$, Fig. 3) was revealed. For sex, women presented bigger N-2 duration for the slow ($F_{37,74} = 7.14$, $p < 0,05$) and fast conditions ($F_{37,74} = 6.31$, $p < 0.05$), and N-1 and clearance duration for the slow

Table 2. Average and standard deviation of the average speed and cadence for the groups of men and women in the three study conditions

	Average gait speed (m/s)			Gait cadence (steps/s)		
	fast	control	slow	fast*	control	slow*
Men	2.59 ± 0.28	2.28 ± 0.41	1.62 ± 0.27	2.14 ± 0.35	1.84 ± 0.31	1.67 ± 0.25
Women	2.54 ± 0.34	2.36 ± 0.32	1.54 ± 0.40	1.98 ± 0.14	1.94 ± 0.10	1.43 ± 0.27

*statistical difference between sexes ($p < 0.05$)

condition ($F_{37,74} = 10.59, p < 0.05$; $F_{37,74} = 6.41, p < 0.05$, respectively).

MANOVA revealed that the average speed and cadence were affected by sex (Wilks' Lambda = 0.869, $F_{2,36} = 7.87, p < 0.001$) and condition (Wilks' Lambda = 0.13, $F_{4,34} = 55.23, p < 0.0001$). An interaction between the factors (Wilks' Lambda = 0.57, $F_{4,34} = 6.36, p < 0.001$) was also revealed. For sex, the speed was higher for men in slow condition ($F_{37,74} = 6.15, p < 0.05$) and fast one ($F_{37,74} = 7.21, p < 0.05$), not indicating any difference in the cadence between the groups (Tab. 2).

Discussion

The results of this study confirm the hypothesis: adaptive locomotor strategies are different between the sexes. Distinct strategies were evidenced for the spatial and temporal variables and cadence in the three task conditions proposed in the study.

For the spatial variables, women presented conservative locomotor strategies evidenced by an increase in the penultimate step length (N-2), last step length (N-1) and in the toe clearance. The greater step length for women is in contradiction to the studies that found greater step length for men [9, 10]. The strategy of increasing the length of the N-2 and N-1 must have been used by women as a way to adjust the movement to the given task [14]. The adjustment in the toe clearance reveals the women's safe attempt to avoid contact and fall while overcoming the high obstacle, the strategies not conventionally used in the studies [12, 23]. These spatial strategies can be understood as a difficulty for the women to couple the motor and the sensorial systems, once the coupling of these systems is essential for the success of the task [13, 24–26]. However, the use of the same strategy for the three-task conditions indicates a reliable standard for the women and can be applied in several gait conditions.

Unlike the women, the men chose to maintain the spatial variables. The men used the same strategy for all tasks. This strategy can be related to the preoccupation in maintaining the stability in the sequence of the

action. Still, this adaptation can be related to a greater flexibility of women in comparison to men – as they have a greater hip flexion [27]. Therefore, men choose to keep the movement pattern to accomplish the task safely adopting a more challenging strategy.

Temporal variables data confirm the conservative strategy of women and the difficulty of coupling the systems. Women showed the need of more visual analysis time in dynamic obstacle conditions represented by an increase of the N-2 and N-1 duration in slow speed condition in comparison to men. Generally, an increase in the duration of the steps with a consequent increase in the time of vision for the planning of the action is a strategy used to increase the time to explore and obtain more relevant information [28]. Specifically, it seems that for the fast speed condition, women increased the clearance time to adjust their movements to the task's speed. As for the slow condition, the increase in the N-2 and N-1 duration and in the clearance indicates that the women decided to wait for the obstacle, they anticipated the obstacle and required some information to adjust the movement to the task. Differently, the men tried to modify the speed as a way to adapt it to the task, confirming earlier findings [1]. An increase in the speed is an adjustment to avoid the increase in the step length [1, 3], which shows that the men's strategy was opposite to that of the women.

For the control condition the women did not modify temporarily their strategy while the men increased the N-2 and N-1 duration. This strategy used by the men can indicate either that their attention on the control condition was not the same as on the other conditions or that the temporal adjustment was prioritized. It is still probable that the men have underestimated the task in the control condition, as the dynamic obstacle conditions offered more risks and required more attention [29].

The different adaptive locomotor strategies used by men and women can be explained by the body constitution and the sensorial and motor integrations. The differences between men and women regarding constitution and anthropometry, which were revealed in this study and confirmed in other studies [1–3], can affect

the strategies. Women have wider hips and the physiological inclination to knock-kneed legs which help relocate the center of gravity downwards [30], making it possible for them to carry out more conservative strategies than men. As for the integration between sensorial and motor systems, it is probable that men and women have used different ways to obtain and use relevant information for the motor planning, which made the online adjustments different, indicating that men were more capable of integrating the information and the movement to achieve the task's goal, requiring fewer adjustments.

Conclusions

We can therefore conclude that the adaptive locomotor strategies used by men and women are different, considering that women are more conservative and need more time to program the action. For the spatial variables, the N-2, the N-1 and the toe clearance were relevant to the efficacy of static and dynamic clearance. As for the temporal variables, the step duration was relevant for the women in the dynamic obstacle conditions, while the men used speed for adjustment.

The lack of analysis of the visual gaze and of the relation between the speed of the individual and the speed of the obstacle was a limitation of the study as it could have revealed other strategies which were not evidenced in this study and could be important for the obstacle negotiation for men and women.

References

- Hurd W.J., Chmielewski T.L., Axe M.J., Davis I., Snyder-Mackler L., Differences in normal and perturbed walking kinematics between male and female athletes. *Clin Biomech*, 2004, 19, 465–472. DOI: 10.1016/j.clinbiomech.2004.01.013.
- Granata K.P., Padua D.A., Wilson S.E., Gender differences in active musculoskeletal stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. *J Electromyogr Kinesiol*, 2002, 12, 127–135. DOI: 10.1016/S1050-6411(02)00003-2.
- Kerrigan D., Casey M.D., Todd M.S., Mary K., Croce U.D., Gender differences in joint biomechanics during walking: Normative Study in Young Adults. *Am J Phys Med Rehabil*, 1998, 77, 2–7.
- Besier T.F., Lloyd D.G., Ackland T.R., Muscle activation strategies at the knee during running and cutting maneuvers. *Med Sci Sports Exerc*, 2003, 35, 119–127. DOI: 10.1249/01.MSS.0000043608.79537.AB.
- Lephart S.M., Ferris C.M., Riemann B.L., Myers J.B., Fu F.H., Gender differences in strength and lower extremity kinematics during landing. *CORR*, 2002, 401, 162–169.
- Malinzak R.A., Colby S.M., Kirkendall D.T., Yu B., Garrett W.E., A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech*, 2001, 16, 438–445. DOI: 10.1016/S0268-0033(01)00019-5.
- Hardy S.E., Allore H.G., Guo Z., Gill T.M., Explaining the effect of gender on functional transitions in older persons. *J Gerontol A Biol Sci Med Sci*, 2008, 54, 79–86. DOI: 10.1159/000115004.
- Kwon I.S., Oldaker S., Schrager M., Talbot L.A., Fozard J.L., Metter E.J., Relationship between muscle strength and the time taken to complete a standardized walk-turn-walk test. *J Gerontol A Biol Sci Med Sci*, 2001, 56, 398–404.
- Callisaya M.L., Blizzard L., Schmidt M.D., McGinley J.L., Srikanth V.K., Sex modifies the relationship between age and gait: A population-based study of older adults. *J Gerontol A Biol Sci Med Sci*, 2008, 63, 165–170.
- Nagasaki H., Itoh H., Hashizume K., Furuta T., Maruyama H., Kinugasa T., Walking patterns and finger rhythm of older adults. *Percept Mot Skills*, 1996, 82, 435–447.
- Patla A.E., Strategies for dynamic stability during adaptive human locomotion: Contribution of visual, vestibular and kinesthetic inputs to maintaining balance in complex environments. *IEEE Eng Med Biol Mag*, 2003, March/April vol. 22, 48–52. DOI: 10.1109/MEMB.2003.1195695.
- Patla A.E., Prentice S.D., Gobbi L.T.B., Visual control of obstacle avoidance during locomotion: strategies in young children, young and older adults. In: Ferrandez A.M., Teasdale N. (eds.), *Changes in sensory motor behavior in aging*. Elsevier, Amsterdam 1996, 257–275.
- Krell J., Patla A.E., The influence of multiples obstacles in the travel path on avoidance strategy. *Gait Post*, 2002, 16, 15–19.
- Mohagheghi A.A., Moraes R., Patla A.E., The effects of distant and on-line visual information on the control of approach phase and step over an obstacle during locomotion. *Exp Brain Res*, 2004, 155, 459–468. DOI: 10.1007/s00221-003-1751-7.
- Lowrey C.R., Watson A., Vallis L.A., Age-related changes in avoidance strategies when negotiating single and multiple obstacles. *Exp Brain Res*, 2007, 182, 289–299. DOI: 10.1007/s00221-007-0986-0.
- Silva J.J., Barbieri F.A., Gobbi L.T.B., Adaptive locomotion for crossing a moving obstacle. *Motor Control* [in press].
- Winter D.A., *The biomechanics and motor control of human gait*. 2nd ed., University of Waterloo, Waterloo 1991.
- Figuroa P.J., Leite N.J., Barros R.M.L., A flexible software for tracking of markers used in Human Motion Analysis. *Computer Methods Programs Biomed*, 2003, 72, 155–165.
- Abdel-Aziz Y.I., Karara H.M., Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In: *Proceedings of the ASP/UI Symposium on Close-Range Photogrammetry*, American Society of Photogrammetry, Falls Church 1971, 1–18.
- Barbieri F.A., Santiago P.R.P., Gobbi L.T.B., Cunha S.A., Dominant and non-dominant support limb kinematics variability during futsal kick. *Port J Sport Sci*, 2003, 8, 68–76.
- Crosbie J., Vachalathiti R., Smith R., Age, gender and speed effects on spinal kinematics during walking. *Gait Post*, 1997, 5, 13–20. DOI: 10.1016/S0966-6362(96)01068-5.
- Zar J., *Bioestatistical Analysis*. 4th ed., Prentice-Hall, Upper Saddle River 1999.
- Chen H.C., Ashton-Miller J.A., Alexander N.B., Schultz A.B., Stepping over obstacles: gait patterns of healthy young and old adults. *J Gerontol A Biol Sci Med Sci*, 1991, 46, 196–203. DOI: 10.1093/geronj/46.6.M196.
- Gérin-Lajoie M., Richards C.L., McFadyen B.J., The negotiation of stationary and moving obstructions during walking: anticipatory locomotor adaptations and preservation of personal space. *Motor Control*, 2005, 9, 242–269. DOI: 10.1016/j.gaitpost.2005.11.001.

25. Patla A.E., Rietdyk S., Visual control of limb trajectory over obstacles during locomotion: effect of obstacle height and width. *Gait Post*, 1993, 1, 45–60. DOI: 10.1016/0966-6362(93)90042-Y.
26. Patla A.E., Understanding the control of human locomotion: a prologue. In: Patla A.E. (ed.), *Adaptability of human gait*. Elsevier, Amsterdam 1991, 13–17.
27. Owolabi E.O., Alawale O.A., Lower limb flexibility norms: some racial, gender and limb symmetrical considerations. *Afr J Health Sci*, 1996, 3, 56–59.
28. Tresilian J.R., The accuracy of interceptive action in time and space. *Exerc Sport Sci Rev*, 2004, 32, 167–173.
29. Bradshaw E.J., Sparrow W.A., Effects of approach velocity and foot-target characteristics on the visual regulation of step length. *Hum Mov Sci*, 2001, 20, 401–426. DOI: 10.1016/S0167-9457(01)00060-4.
30. Weineck J., *Optimales training*. Perimed Fachbuch, Erlange 1990.

Paper received by the Editors: June 17, 2009.

Paper accepted for publication: August 25, 2010.

Address for correspondence

Profa. Dra. Lilian Teresa Bucken Gobbi
Universidade Estadual Paulista – UNESP – IB –
Rio Claro
Laboratório de Estudos da Postura e da Locomoção –
Departamento de Educação Física
Avenida 24-A, 1515 - Bela Vista–CEP:
13.506-900- Rio Claro/São Paulo/Brasil
e-mail: ltbgobbi@rc.unesp.br