



ANALYSIS OF PEAK TIBIAL ACCELERATION DURING GAIT IN DIFFERENT CADENCES

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ABSTRACT

Purpose. The gait is the most common human movement, a functional task that requires complex and coordinated interactions of the body. This activity has been the subject of various studies, both in relation to descriptions of typical body movements as in pathological conditions and therapeutic interventions. The objective of this study was to describe and analyze the variation of peak acceleration in the tibia by means of accelerometers during the gait cadence induced in normal subjects. **Basic procedures.** Nine subjects walked on a catwalk on a straight line for 8 meters at 4 km/h ($\pm 5\%$), 5 km/h ($\pm 5\%$) and 6 km/h ($\pm 5\%$) using uniaxial piezoelectric accelerometers with scale 7g set at the midpoint of both tibiae. **Main findings.** It was observed that there was no difference in peak acceleration between dominant and non-dominant limbs, however, there was significant difference ($p < 0.05$) among all the velocities with which the subjects were analyzed. **Conclusions.** It is suggested that the variation of 1 km/h is enough to change the peak acceleration of the tibia.

Key words: gait, tibial peak acceleration, different cadences

Introduction

The gait is the most common human movement [1], a functional task that requires coordinated and complex interactions between many of the major joints of the body [2, 3], in particular the lower limbs [2].

This activity has been the subject of various studies, both in relation to descriptions of typical body movements as in pathological conditions and therapeutic interventions [2, 4].

In almost all movements of human locomotion, the ground reaction force is acting on the subject. This force of ground reaction is an application of Newton's third law of motion, also known as action–reaction law. The person exerts a force on the ground with a certain intensity, and the ground returns to the individual a force of equal intensity, but in the opposite direction [5].

According to Winter [1], the most common force acting on the human body is the force of ground reaction, which acts while it is in the static position, walking or running. This vector of force consists of a vertical component and two horizontal components acting parallel to the surface of the platform of strength or of the measuring instrument. These shared horizontal forces are usually described as fore-aft and medial-lateral.

According to Perry [6], the normal pattern of vertical

forces obtained during the support phase at a normal running speed of 1.36 m/s has two peaks separated by a valley. Thus, the value of the peaks is close to 110% of the body mass, while the force in the valley is around 80%.

Viel [3] defines the force of shear as a force of laceration that is exerted when two solid bodies are animated by inverted parallel sliding movements, causing then a distension in the means of union (joint capsule, ligaments). Perry [6] affirms that when the force of shear is excessive it can cause injuries in the bone structures, muscle and ligaments.

Nigg and Herzog [7] argue that such a force can be analyzed by accelerometry, and they cite the work of Gage (1967), where accelerometers were used during the gait to check the vertical and horizontal accelerations of the head, trunk, hip and ankle.

Accelerometers are sensors that measure acceleration. Typically, these are made of a reaction mass suspended by a stationary structure, and the same can be viewed as a mass-spring system. The force exerted by the weight is balanced by the spring, the displacement allowed by the spring being proportional to the force applied, and the acceleration of the body proportional to the displacement of the mass [8].

In piezoelectric accelerometers the mass is attached to a piezoelectric crystal. When the body undergoes a vibration, the mass follows the laws of inertia and the crystal is subjected to traction and compression forces, generating loads, and this force is proportional to the second Newton's law [8].

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Since 1988, studies of Lafortune and Hennig have described the tibial accelerometry during walking and running [9, 10].

For the importance of movement, the aim of this study is to describe and analyze the variation of peak acceleration in the tibia by using accelerometers during the gait cadence induced in normal subjects.

Material and methods

This research was reviewed and approved by the Ethics Committee on Human Research at the University of the State of Santa Catarina – UDESC, Florianópolis-SC reference number N° 184 on October 22, 2008.

Study participants

According to Cervo and Bervian [11], the population of scientific research comprises a group of people who are potential subjects in various studies, and the participants in this study belong to this group.

The sample was intentionally non-probabilistic, so 9 male subjects, with fixed residence in Florianópolis-SC, were selected. The criteria for inclusion in the study were as follows: healthy individuals interested in participating in the research with an average age of 21.67 (± 3.57) years, academics from the University of Santa Catarina, Center for Health Science and Sport. The criteria for exclusion from the study were as follows: subjects who used orthosis or prosthesis in the lower limbs, who had presented a problem in the lower limbs in the previous six months or were using any medication that could interfere with balance and/or muscle tone.

Location

Data acquisition was performed at the Biomechanics Laboratory of CEFID-UDESC in Florianópolis-SC.

Instruments for data collection

For this study two uniaxial piezoelectric accelerometers with scale 7 g were used, sensitivity 952.1 mV/g, cross sensitivity < 5%, frequency range from 0.4 to 0.6 kHz. (1 × 1 × 1 cm, mass = 4.6 g – Brüel & Kjær model DeltaTron ® 4507 B 005, Fig. 1).

Variables analyzed

The peak acceleration was analyzed during gait through the software developed in LabVIEW environment (G-Power-Analysis v0.3). The first two and last two peaks of each sample were excluded from the analysis. These data were exported to a spreadsheet in

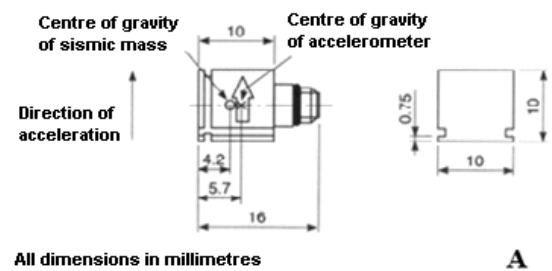


Figure 1. (A) Accelerometer Brüel & Kjær, model DeltaTron ® 4507 B 005. All dimensions are in millimeters. The “arrow” shows to the direction of acceleration (image taken from the manual of the accelerometer), (B) Set of four accelerometers Brüel & Kjær, model DeltaTron ® 4507 B 005 and the signal conditioner

SPSS 17.0, where an exploratory descriptive statistics was performed, followed by one-way ANOVA and Scheffe post hoc test.

Procedure for data collection

First, the objectives of the study and the sequence of evaluations were presented to the subjects. Then, the participants were asked to sign an informed consent form. Next, the identification form was filled, which contained anthropometric information, as well as a questionnaire about the laterality of the lower limbs. Afterwards, we asked the subjects to put on swimming trunks (in the locker room of the laboratory of biomechanics) and to sit on a chair so that accelerometers could be positioned on the lower limbs. Two accelerometers were used: one at the midpoint of the dominant member tibia and another at the midpoint of the non-dominant member tibia.

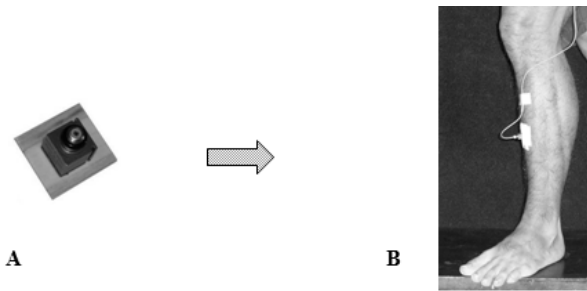


Figure 2. (A) Accelerometer fixed on balsa wood using double-sided tape before being engaged in the subject’s leg, (B) Accelerometer fixed in the middle third of the tibia

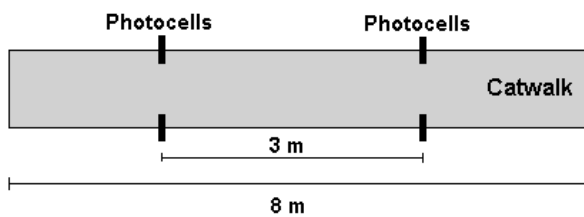


Figure 3. Catwalk where individuals walked for the signal acquisition: the system of photocells to control the speed was positioned 2.5 m from the start and end of the catwalk

Accelerometers were fixed with double sided adhesive tape on the balsa wood (wood used in airplane models, in order to avoid injury to the skin, since the accelerometer has corners that may damage the tissue) and this was fixed on the skin with tape (Fig. 2). The subjects wore a vest where, in the pockets of it, were placed two signal conditioners that were linked to the two accelerometers fixed on the lower limbs. A thin wire connected each accelerometer to its signal conditioner without interfering with movement of the subject. The subjects walked on a catwalk (on a straight line for 8 meters) at 4 km/h ($\pm 5\%$), 5km/h ($\pm 5\%$) and 6 km/h ($\pm 5\%$); the photocells that monitored the speed were positioned two and a half meters from the start and end of the catwalk (Fig. 3). The attempts where the subjects did not achieve the target speed were discarded. This course was conducted with subjects barefoot and repeated 5 times for each speed. The peaks of tibial acceleration were measured while the subjects walked on the catwalk. After completion of the course, the accelerometers were removed from the subjects and assessment was completed.

Results

Initially, we compared the peak acceleration of the tibia of the dominant and non-dominant limb of each subject in each of the three speeds adopted. As can be seen by comparing the averages with t-test (Fig. 4), the

difference between the limbs is not significant ($p > 0.05$), there is no need to differentiate between dominant and non-dominant limbs. Therefore, all further analysis was made with both data put together.

Table 1 shows the average of peak tibial acceleration in the lower dominant and non-dominant limbs, the standard deviation and the average trimmed by 5% at the extremes at the speed of 4 km/h, 5 km/h and 6 km/h. At all speeds there is a similarity between the regular average and the trimmed average, suggesting that there were no values of peak acceleration high enough to raise or lower the average.

The statistical test Analysis of Variance (ANOVA) one-way was performed (Tab. 2), where significant difference, in at least one of the groups, was observed. Therefore, Scheffe post hoc test was applied to de-

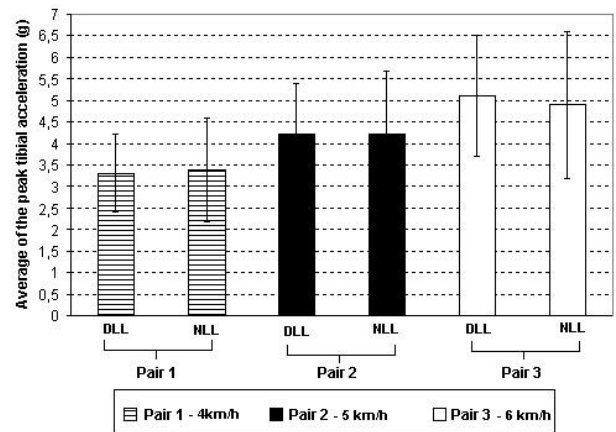


Figure 4. Average of the peak tibial acceleration in g (gravity) and standard deviation in the dominant lower limb (DLL) and non-dominant lower limb (NLL) at speeds of 4, 5 and 6 km/h

Table 1. Comparison between the average (\bar{x}) and the trimmed average with less 5% of the extremes (TA -5%) of peak acceleration in the dominant and non-dominant limb tibia with the person walking at 4 km/h, 5 km/h and 6 km/h; the similarity of values is visible. "s" means the standard deviation

Subject	4 km/h		5 km/h		6 km/h	
	\bar{x} (s)	TA -5%	\bar{x} (s)	TA -5%	\bar{x} (s)	TA -5%
1	1.6 (0.3)	1.5	2.1 (0.4)	2.1	3.1 (0.7)	3.1
2	2.7 (0.5)	2.7	4.3 (1.6)	4.2	4.5 (1.8)	4.4
3	5.2 (0.9)	5.3	6.5 (0.7)	6.6	7.7 (0.8)	7.7
4	3.8 (0.6)	3.8	4.6 (0.7)	4.6	6.6 (1.1)	6.7
5	3.2 (0.7)	3.3	3.8 (0.8)	3.8	5.2 (1.7)	5.2
6	3.9 (0.8)	3.9	4.9 (1.3)	4.8	4.7 (1.1)	4.6
7	4.0 (0.3)	4.0	4.8 (0.6)	4.8	5.1 (0.7)	5.6
8	3.5 (0.4)	3.5	4.1 (0.7)	4.1	4.5 (0.6)	4.5
9	2.7 (0.6)	2.7	2.8 (0.5)	2.7	3.3 (0.5)	3.2

termine between which groups the difference occurred. In Table 3 significant difference in all groups can be observed ($p < 0.05$). This suggests that the variation of 1 km/h is enough to cause significant change in peak tibial acceleration.

Table 2. One-way ANOVA between the different speeds

	SQ	df	MQ	F	<i>p</i>
Between groups	318.9	2	159.4	67.8	0.001
Within groups	1584.6	674	2.3		
Total	1903.4	676			

SQ – sum of squares, df – degrees of freedom, MQ – mean square, F – F test, *p* – significance value

Table 3. Scheffe post hoc test where there is significant difference between all the different speeds ($p < 0.05$)

		Multiple comparisons Scheffe			
Speed	Speed	Average difference	<i>p</i>	95% Confidence interval of the difference	
				Upper	Lower
4 km/h	5 km/h	-0.9	0.001*	-1.3	-0.6
	6 km/h	-1.7	0.001*	-2.0	-1.3
5 km/h	4 km/h	0.9	0.001*	0.6	1.3
	6 km/h	-0.7	0.001*	-1.1	-0.4
6 km/h	4 km/h	1.7	0.001*	1.3	2.0
	5 km/h	0.7	0.001*	0.4	1.1

* The average difference is significant at a .05 level.

Discussion

To meet the objectives proposed in the study, subjects underwent three procedures: first, they walked at a speed of 4 km/h, then 5 km/h and finally, at 6 km/h, where each subject was numbered from 1 to 9.

By comparing the peak tibial acceleration of the dominant and non-dominant limbs for each subject using the t-test, it is verified that there is no need to analyze the limbs separately in the data analysis, as there was no statistical difference between them. When comparing the average peak tibial acceleration with the peak tibial acceleration trimmed by 5% at the extremes – at all speeds – a similarity is observed, suggesting that there were no values of peak acceleration high enough to raise or lower the average.

There was significant difference in all speeds ($p < 0.05$). This suggests that the variation of 1 km/h is enough to cause a significant change in peak acceleration of the tibia. When the study of Lafortune and Hennig [12] – speed of 1.5 m/s (5.4 km/h) – is compared

with this study, by t-test, no significant difference is found at the speeds of 5 and 6 km/h ($p > 0.05$), but a significant difference is found when compared to speed of 4 km/h ($p < 0.05$), confirming the findings of this study, which suggests that from 1 km/h onward there is already a significant change in peak tibial acceleration (Tab. 4).

But when compared with the study by Lafortune et al. [13], where speed was 1.05 m/s (3.78 km/h), there was significant difference for all three speeds adopted in this study, including the speed of 4 km/h (Tab. 5); considering that the population and conditions of the sample were similar, it confirms again the findings of this study and indicates that a smaller percentage of the variation in speed may be sufficient to generate a significant difference in peak tibial acceleration.

Table 4. T-test between the average peak tibial acceleration found by Lafortune and Hennig [12] and the averages found at speeds of 4, 5 and 6 km/h

Test value = 4.68 g						
	<i>t</i>	gl	<i>p</i>	Average difference	95% Confidence interval of the difference	
					Lower	Upper
4 km/h	-3.7	8	0.005*	-1.3	-2.1	-0.5
5 km/h	-1.0	8	0.321	-0.5	-1.5	0.5
6 km/h	0.6	8	0.535	0.3	-0.8	1.5

Table 5. T-test between the average peak tibial acceleration found by Lafortune, Lake and Hennig [13] and the averages found at speeds of 4, 5 and 6 km/h

Test value = 8.80 g						
	<i>t</i>	gl	<i>p</i>	Average difference	95% Confidence interval of the difference	
					Lower	Upper
4 km/h	-15.4	8	0.001	-5.4	-6.2	-4.6
5 km/h	-10.4	8	0.001	-4.6	-5.6	-3.6
6 km/h	-7.6	8	0.001	-3.8	-4.9	-2.6

Table 6. T-test between the average peak tibial acceleration found by Wüst, et al. [14] and the averages found at speeds of 4, 5 and 6 km/h

Test value = 2.80 g						
	<i>t</i>	gl	<i>p</i>	Average difference	95% Confidence interval of the difference	
					Lower	Upper
4 km/h	1.6	8	0.145	0.6	-0.2	1.4
5 km/h	3.2	8	0.012	1.4	0.4	2.4
6 km/h	4.4	8	0.002	2.2	1.0	3.4

In the study by Wüst et al. [14], a subject walked at 5 km/h in conditions similar to those of this work. The average peak tibial acceleration was 2.80 g, approaching the value obtained at 4 km/h in this study, the differences being significant for all other velocities (Tab. 6). However, the gait in that study was performed on a treadmill. Milani et al. [15] and Lafortune et al. [16] have already discussed the existence of a significant difference in peak acceleration between walking held on the ground and on the treadmill. The authors also suggest the project “Projeto Final de Instrumentação e Aquisição de Sinais”, Instituto Superior Técnico (Instrumentation and Signal Acquisition Final Project, Superior Technical Institute) should continue for further explanation about the difference found between this study and Wüst et al. study [14].

Conclusions

Based on the proposed objectives, one can observe that the values of peak tibial acceleration during gait in normal subjects walking at speeds of 4, 5 and 6 km/h did not differ statistically between dominant and non-dominant limbs, and in the t-test, p was higher than 0.05.

On the other hand, when the peak acceleration was compared at different speeds, it was observed that an increase of 1 km/h was enough to change the peak acceleration of the tibia significantly, as shown by the comparison test of averages applied: ANOVA.

Comparing the results of this study to the literature on the speed of 5.4 km/h, one can observe that this study is consistent, since by t-test application no significant difference was found at the speeds of 5 and 6 km/h ($p > 0.05$). A significant difference was found when compared to speed of 4 km/h ($p < 0.05$), suggesting that, starting from 1 km/h, there is already significant change in peak acceleration of the tibia.

But when the speed of 5 km/h is correlated with the gait performed on the treadmill, it is observed that the peak values of acceleration are similar to the values obtained at 4 km/h in this study; but the kinetic and kinematic differences between gait on the ground and on the treadmill are already known.

To further complement the study, there is suggested a population expansion and a reduction in the speed range.

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