Introduction

Frailty is a syndrome that occurs principally in the elderly. People who suffer from it have their physiological reserves and adaptive capacities diminished, therefore, it is more difficult for them to recover from a stressful event. They are more vulnerable to negative outcomes such as disability, dependency, institutionalization, falls, injuries, acute illness, hospitalizations, slow or incomplete recovery from illness and/or hospitalization and mortality [1,2,3,4]. Consequently, this syndrome significantly affects the functionality of individuals.

The etiology of frailty is unknown, however, it is known that various paths lead to it. This, among other factors such as its pathophysiology, makes frailty a difficult condition to diagnose. There have been multiples attempts, some of the most popular are the Frailty Phenotype (FP), proposed by Linda Fried et al. [1], the Frailty Index (FI) and the Clinical Frailty Scale (CFS), both proposed by Rockwood et al. [2]. FP quantifies the loss of physical functionality, and is based on 5 components: unintentional weight loss, weakness as measured by handgrip strength, experience of exhaustion, slow average gait velocity and low physical activity. However, it does not consider some other aspects that also affect the functionality for instance social behaviour, emotional and cognitive. The FI is a 70-item scale which considers a wider spectrum, nevertheless, is not efficient for being implemented in the clinical practice because is long time consuming and expensive. Finally, the CFS is based on clinical judgment, the clinical history of the patient and a clinical examination. This scale has had good results when applied in the clinical environment, but is subjective to the geriatrician who performed the evaluation []. Those scales do not include physiological information which could contribute to the objectivity of the quantification of frailty.

We made a study with the purpose of analysing physiological alterations in frail and non-frail elderly people. This investigation includes several variables, from anthropometric measurements to physiological time series and gait dynamics. This article is part of a series of articles in which we will describe the physiological alterations, the loss of the regulatory and/or compensatory systems of the different variables measured in frail and non-frail elderly people. In the present paper, we will discuss the results related to gait dynamics.

Loss of functionality is very related to frailty, in this context, average gait speed has been widely studied, actually, is one of the 5 items of Fried Index [1]. To measure this, an elderly must walk a 4.5m distance and then the average of their gait speed is calculated. If the person has a slow gait speed is considered frail, as it is a clear sign of fatigue. However, that distance could be short for some elderly with a slight degree of frailty, because that test could not represent a sufficient stressor for fatigue to become evident.

The reason why the average gait speed lows is still unknow, it could be for various aspects: the loss of muscular mass due to sarcopenia, the loss of muscular elasticity, equilibrium failure, the result of poor compensation of various physiological systems or a combination of some of those factors.

In this article we will explore on the one hand 1) what happens with the average gait speed associated variables, that is, step length and cadence (see Ec. 1) and, on the other hand, 2) how the triaxial accelerometry (sagittal, medio-lateral and vertical) gets modified in frail elderly people.

$$< v > = C * l$$

C = Cadence and l= step length

Methods section

Participants

This study was carried out from September 2016 to April 2017. 76 Mexicans participated, we divided them in four groups: i) young control adults (C1) 19-29yo (N=25), ii) middle-aged control adults (C2) 30-59yo (N=15), iii) non-frail elderly adults (nF) >60yo (N=16) and iv) frail elderly adults (F) >60yo (N=20). The elderly were outpatients of the Hospital General de México (HGM), all of them were evaluated by a geriatrician with the CFS [1]. In order to have a more realistic sample of frailty, we included both genders and people with a varied clinical history. The criteria to exclude people were those with a physical, auditory or visual limitation that put them at risk during the exercise test. Also, a severe cardiac failure as well as severe supraventricular alteration or monomorphic ventricular extrasystole. C1 were medical students and C2 were accompanying family members of the elders.

All participants signed a letter of confirmed consent. This protocol was approved by the ethics committee of the Hospital General de México “Dr. Eduardo Liceaga” (HGM) with the registry number DI/14/110-B/03/002. All the participants enrolled in the study on a voluntary basis.

Materials

We used a Zephyr Bioharness 3.0, which was placed below the left armpit, for raw data of 1 channel of electrocardiogram (ECG), the breathing wave form, and gait dynamics using 3-axial accelerometry. From those series, we studied derived variables such as heart rate (HR), breathing rate (BR), breathing amplitude (BA) and posture.

We collected other physiological data such as body temperature, blood pressure, and blood oxygen saturation. Additionally, we have a video from backward during the walking test of all of the participants. These variables will be discussed in later articles.

Design and procedure

This study consisted in three phases, a 160m walk and two rests, one before and the other after. First of all, the test was explained to the patients and if they agreed they signed the consent letter. After that, the measuring devices were placed by the same nurse and a questionnaire with anthropometric, clinical history, activities and habits data was applied.

The test began with 5 minutes of standing rest, after that, each of the participants made a 160m route on a rectangular flat terrain that was inside one of the HGM's surgical towers, each person started at the same point and made the journey until they reached the initial point where they turned in the opposite direction and went back to the same initial point. Each person made the walking at their own pace. Finally, the subjects rested on their feet for 5 minutes more.

Accelerometry methodology

In accelerometry, several parameters are studied (average, variability, maximum (peak) or minimum (min) values, symmetry, regularity), in this article, we concentrated in peak and min values of accelerometry. We used the peak and min values given by the Bioharness 3.0 software. To corroborate the validity of that data, we took the raw series of accelerometry and for every axis we calculated de maximum and minimum values for every 1 second interval. That time interval is the one that uses the software and also it corresponds with the approximated time to take a step, therefore, we analysed the maximum or minimum acceleration of every step.

Results

---------------------→ Fig. 1 goes here ←-------------------

---------------------→ Fig. 2 goes here ←---------------------

---------------------→ Fig. 3 goes here ←---------------------

In Fig. 1, appears raw time series of accelerometry of three representative cases of C1 (a), nF (b) and F (c) groups. It can be seen how the gait patterns are more defined for C1 and nF cases, although there is a decrease in accelerations with age and more noticeably with frailty.

In figure 2 (a) it can be seen that the average of gait speed is clearly lower for frail elderly people than for the control groups and non-frails. Further, horizontal gridlines show that a part of the frail group walked with speeds catalogued as frail people according to Fried criteria [1]. Additionally, this group presents a higher dispersion of data.

According to equation [1], the speed of gait depends on the product of two factors: cadence and length of steps. The first one is on Fig. 2 (b), it can be seen that cadence increases with age but not with frailty, although the dispersion in data increases in a general way. On the other hand, in (c) the length of steps is shown, this quantity is very similar for C1 and C2 and then diminishes for nF group and a bit more drastically for F group.

In terms of accelerometry, we found in Fig. 3 a) that sagittal accelerometry is almost the same for C1, C2 and nF groups, however, it decreases significantly for frail group. The medio-lateral axis in b) figure shows a different behaviour, in this case, there is a tendency to increase acceleration. Finally, vertical axis shown in c) is the same for control groups but begins to diminish for non-frail group and diminish even more in the frail group. As well as for sagittal acceleration, vertical also had a significant difference between frail group and each of the rest of groups.

Discussion

We obtained the well-known result of low speed of gait in the frail elderly (0.6 m/s). Graphic of Fig.2 shows that the average of gait speed is very similar for C1, C2 and nF group (see Table…), it could be said that the speed of gait of C2 and nF groups is as functional as the one of the younger group, however, the one of the frail group is much lower. Our interpretation of this is that middle aged controls and non-frail elderly still have physiological reserves that can be used to help to maintain a good gait speed despite the age. That does not happen for frail people who do not have enough physiological reserves so they do not compensate their deficiencies and their speed of gait diminishes affecting their functionality.

In order to answer why the speed of gait diminishes in frail people, we studied the two related speed quantities, the cadence and step length. We obtained that gait speed increases from C1 to C2 due to the increase of cadence of C2. Then, gait speed of nF is the same for C2 because although the cadence increases, the step length diminishes. In the case of frail elderly, both the cadence and the step length decrease having as a consequence the drop of the gait speed.

Further, in Fig. 2 (a) there are two horizontal gridlines that show the average of gait speed according to Dra Fried index. We found that some of our frail participants walked with not so slow speeds (the range between 0.7 m/s and 0.9 m/s), however, according to CFS they are frail, it could be that those individuals have a low degree of frailty, anyway, they have speeds that distinguish them significantly from the other groups, this could be because the test we proposed (walk of 160m), involves a greater challenge than short distances (approximately 4.5m), which allows better distinguish between groups.

In general, it can be seen from Fig. 2 (a), (b) and (c), that frail group have a greater dispersion on all the variables, this could be due to heterogeneity of pathophysiologies and degrees of frailty, despite this, the speed of gait and step length are significantly different between frail and each of the other groups. The same happens for cadence except between frail and non-frail groups.

In Fig. 3 (a) and (c) there is a trend to decrease, that is, acceleration in sagittal and vertical axis get loss with frailty. The opposite happens for lateral axis, it tend to increase. These changes in the behaviour of these variables suggest that they are variable of different types.

The forward movement is limited and they advance little, in the vertical case the same thing happens, the frail people do not have enough muscular strength in the calf that helps them get up off the ground so vertically there is not much movement either. These two variables were reduced, so the frail elderly in an attempt to have a more efficient gait, begin to move more laterally to be able to advance a little more and not to fall, that is, they try to maintain their balance by opening their lateral axis.

Conclusions

In this article, the speed of the gait was evaluated, the well-known slowdown result was reproduced in frail older adults. In addition, other parameters (cadence and step length) helped to understand more deeply the way they walk. It was observed that the frail elderly walk with steps noticeably smaller than others older non-frail adults and controls. They try to compensate for this deficiency by taking a greater number of steps, however, other factors (which could be physiological) do not allow them to take too many steps to compensate for the steps of small length and consequently its average speed of travel decreases.

On the other hand, the accelerometric variables allowed us to find a walking pattern where frail older adults advance little forward and vertically but they begin to lateralize to stabilize and achieve a little more progress. It seems that they are regulating their gait to have a lower risk of falling.

We found loss of compensation and regulatory mechanisms in the gait due to loss of physiological reserves.

References

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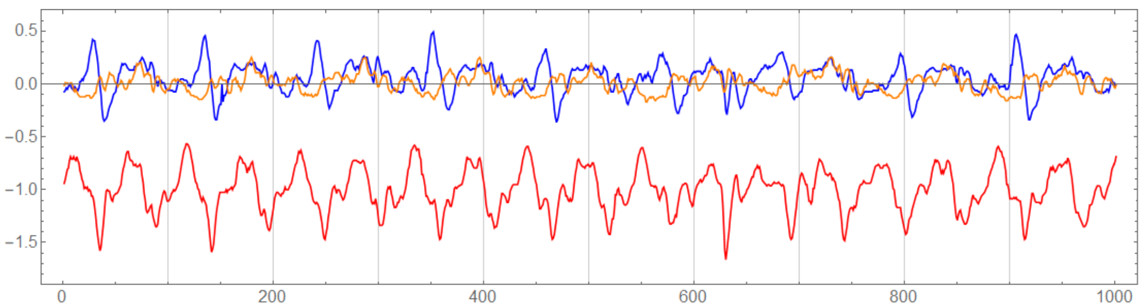
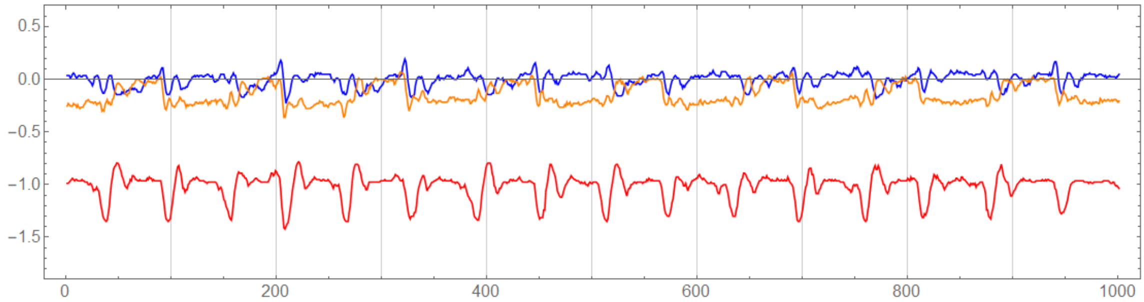
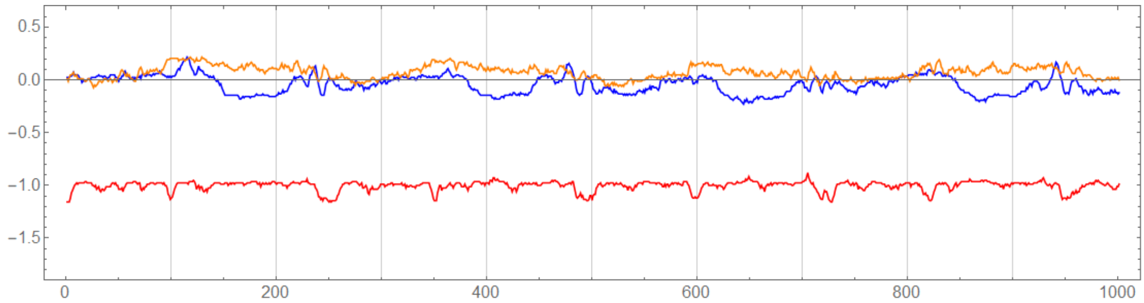


(a) Triaxial accelerometry of a 21 yo control subject LM21f



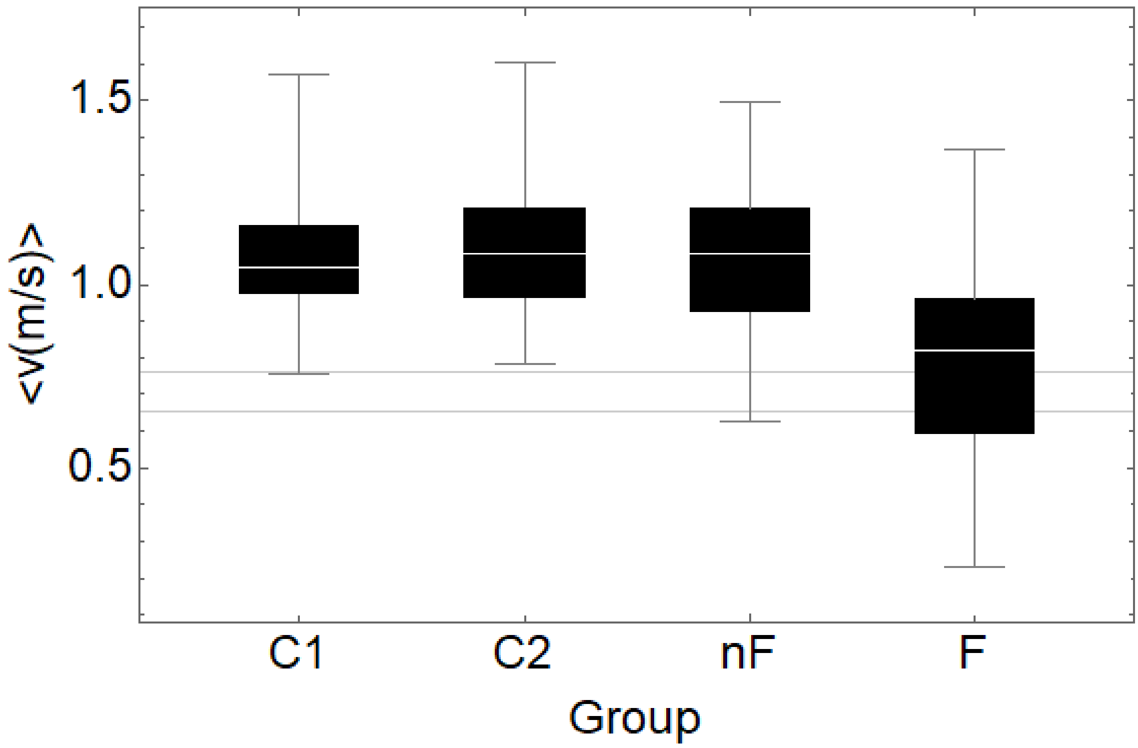
(b) Triaxial accelerometry of a 84 yo non-frail ederly EE84f



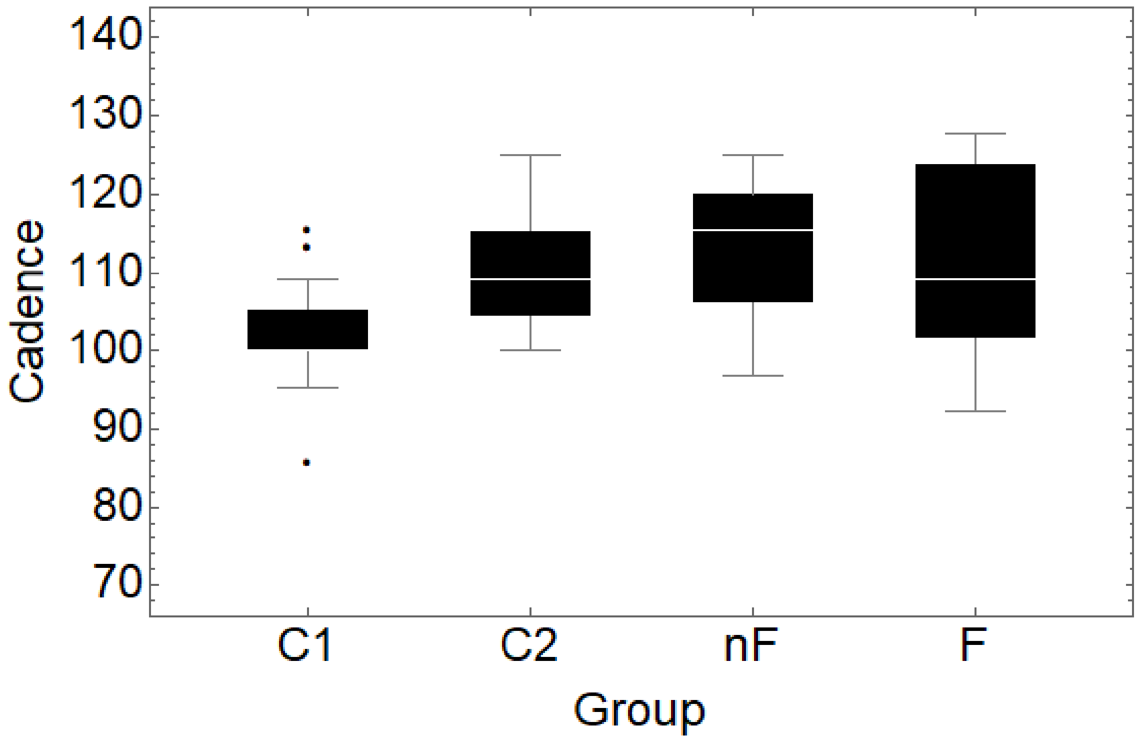
(c) Triaxial accelerometry of a frail elderly EB85m

Figure 1. 10 seconds fragments of triaxial accelerometry at the beginnig of a 160m walk of a) a female young control subject of 21 yo, b) a female non-frail elderly of 84 yo and c) a male frail elderly of 74 yo. These series were measured by the accelerometer of a Bioharness 3.0 []. In red, is shown the sagittal axis, in orange, the medio-lateral axis and in blue, the vertical axis.

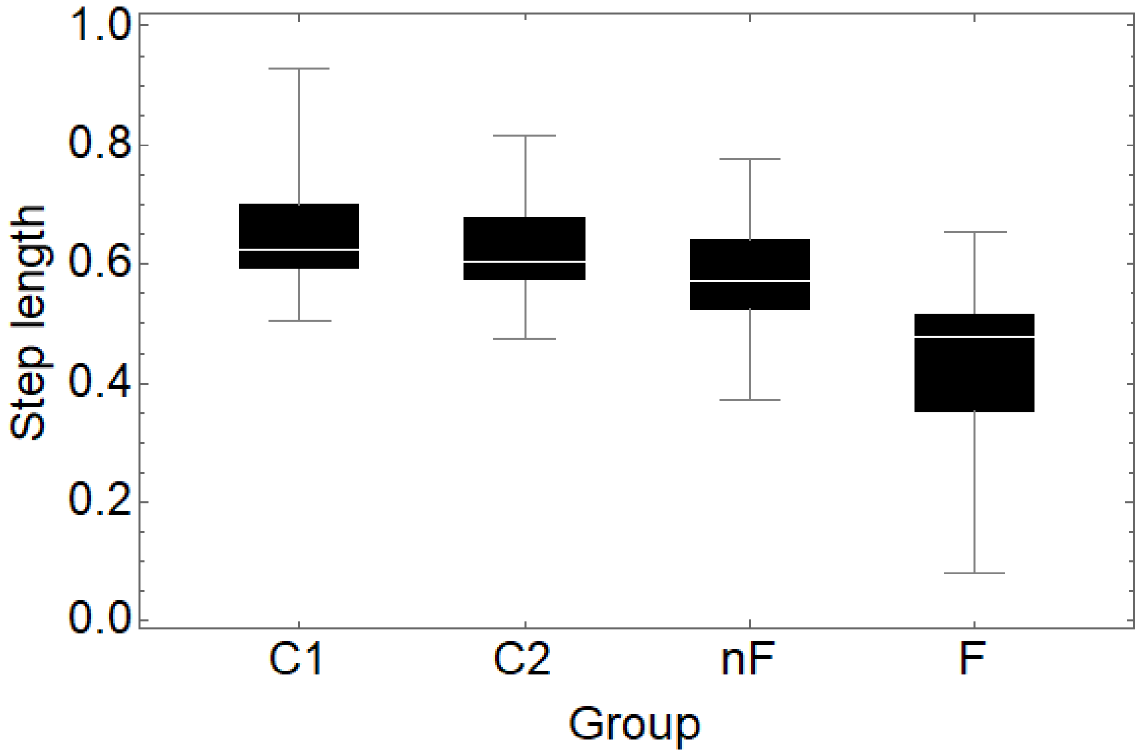
The vertical gridlines in each graphic are situated every one second interval.



(a) Average gait speed

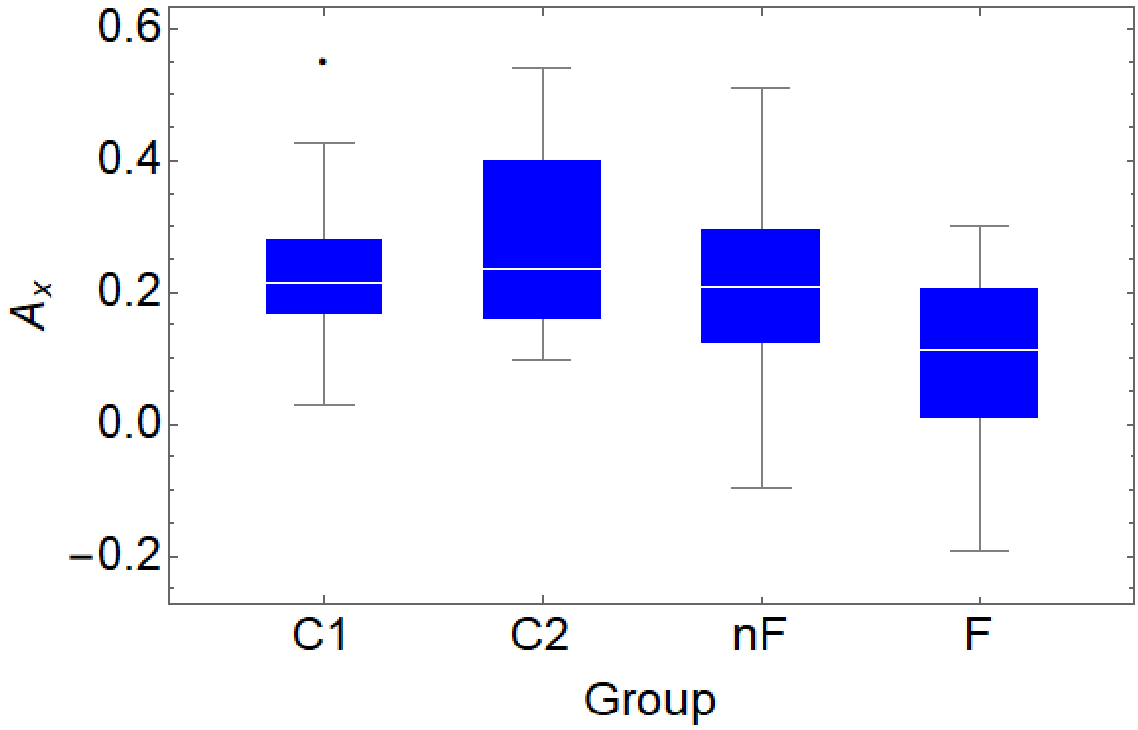


(b) Cadence

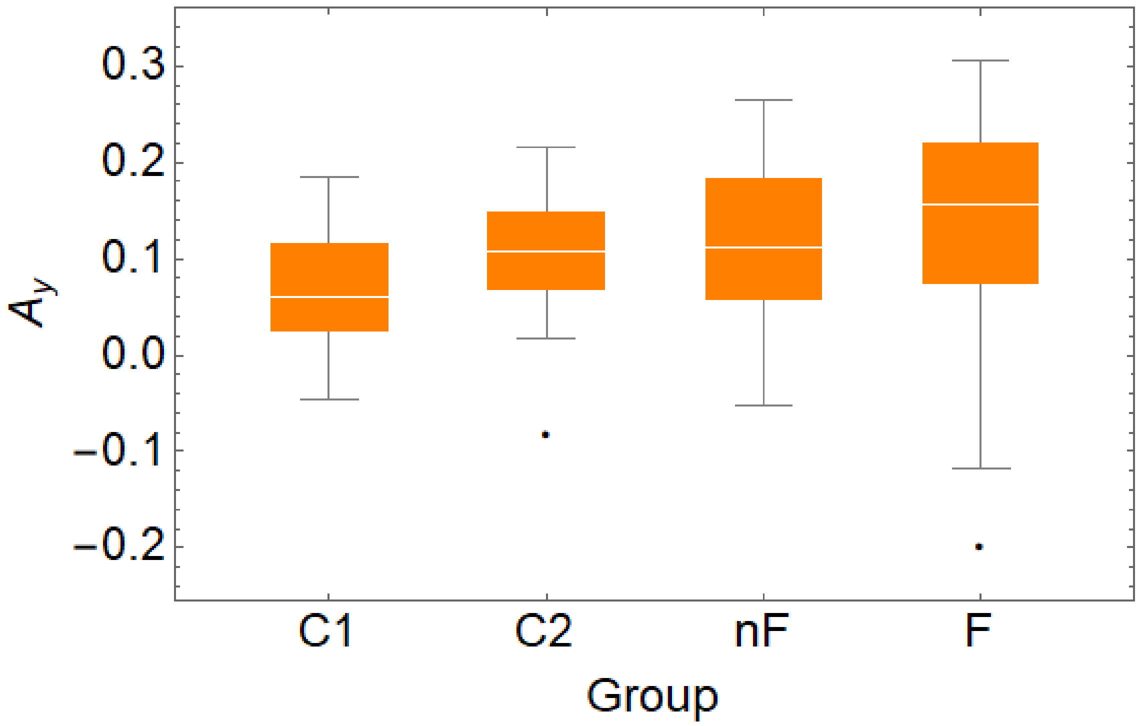


(c) Step length

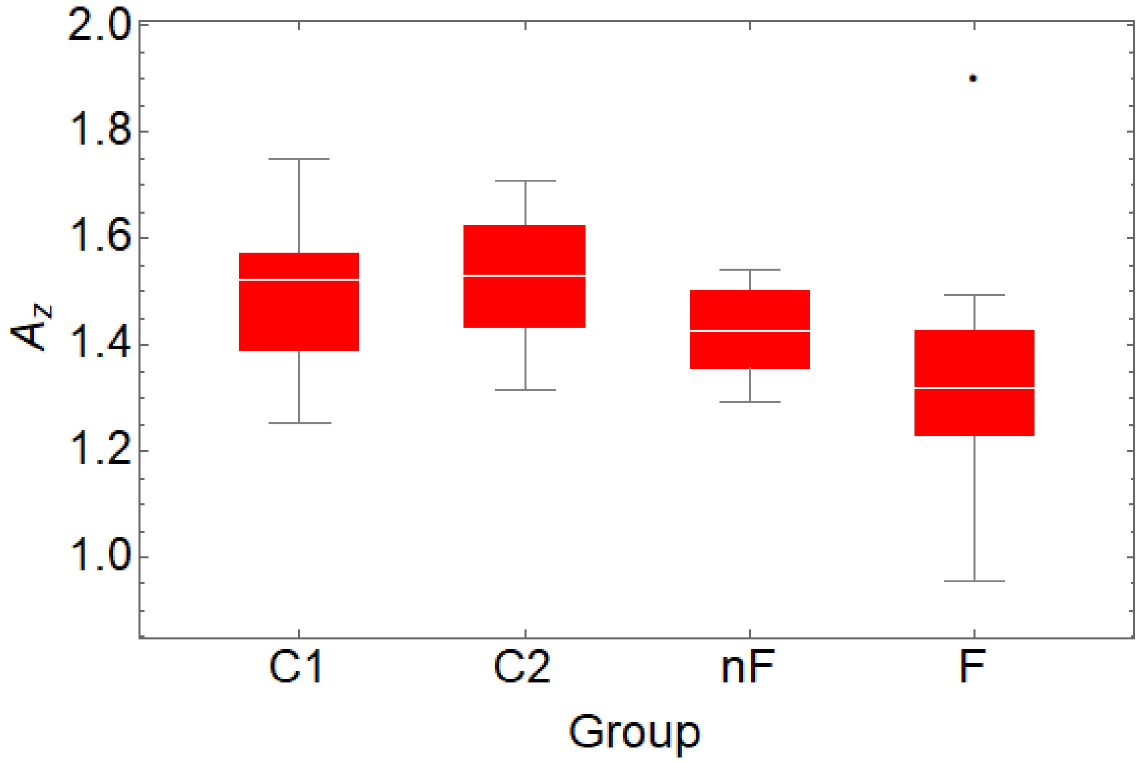
Figure 2. These whisker plots show in (a) the average gait speed in meters per seconds, in (b) the cadence (number of steps per minute) and in (c) the step length for the 4 groups of participants: C1 is the young control group, C2 is the middle age control group, nF is the non-frail elderly group and F is the frail elderly group. In (a), the horizontal gridlines show the average of gait speed according to Fried index, the one above corresponds with men and women with lower height than 1.73m and 1.59m respectively while the lower line is for higher heights. In (b) it is shown the cadence that is the number of steps per minute. This quantity was calculated from the autocorrelation function []. In (c) appears the step length, which is a derived measure estimated from the ratio between velocity and cadence.



(a) Peak acceleration of sagittal axis



(b) Peak acceleration of lateral axis



(c) Minimum acceleration of vertical axis

Figure 3. In a) and b) the average peak accelerations of the sagittal and mediolateral axis are shown, in c) appears the minimum acceleration of the vertical axis.