Correlation between vertical ground reaction force and knee angular velocity of young and elderly individuals during stair descent

Danilo de Oliveira Silva[1,3]
Débora Cristina Thomé[2]
Amanda Schenatto Ferreira[2,3]
Fernando Amâncio Aragão[2,3]

Abstract

Objective: To analyze the relationship between vertical ground reaction force and knee angular velocity of young and elderly persons during stair descent. *Methods:* The sample consisted of two groups: the Elderly Group (EG; n=10) and the Young Group (YG; n=16). A ladder test consisting of seven steps, with a force plate coupled to the fourth step to acquire kinetic data and determine the moment of foot contact with the step, was used, as well as a system of three-dimensional kinematics with four infrared cameras. The volunteers descended the stairs continuously, at a self-selected speed and pace. The Student's t-test was used for independent samples and the Pearson correlation test was used to test the correlation of the variables, with a level of significance of $\alpha=0.05$. *Results:* The results showed a significant difference between the YG group (240.7±10.5 g/s) and the EG group (186.4±13.2 g/s) for mean peak knee angular velocity. Regarding peak vertical force (Fz), YG had a higher magnitude of force (1.39±0.03) than EG (1.15±0.02), with a significant difference between the groups ($p=0.00$). The results also showed a positive correlation between variables (r=0.4). *Conclusion:* The results indicate that elderly persons have a lower knee angular velocity and lower vertical force during stair descent than young people and that there was a correlation between the variables.

Key words: Biomechanical Phenomena; Kinetics; Aging.

[1] Universidade Estadual Paulista, Faculdade de Ciências e Tecnologia, Programa de Pós-graduação em Fisioterapia, Laboratório de Biomecânica e Controle Motor. Presidente Prudente, SP, Brasil.

[2] Universidade Estadual do Oeste do Paraná, Centro de Ciências Biológicas e da Saúde, Departamento de Fisioterapia. Cascavel, PR, Brasil.

[3] Universidade Estadual do Oeste do Paraná, Centro de Ciências Biológicas e da Saúde, Departamento de Fisioterapia, Laboratório de Pesquisa do Movimento Humano. Cascavel, PR, Brasil.

Correspondence
Fernando Amâncio Aragão
E-mail: feraaragao@gmail.com

INTRODUCTION

During the aging process a series of morphological changes occurs, among which is the decline of the musculoskeletal system, which results in a loss of both force and muscle mass, whether by atrophy or by a reduction in the number of muscle fibers.[1,2] This process is not only specific to each individual, but also to each muscle group.[3] This loss, particularly in the lower limbs, especially effects walking, which in turn limits the functionality of the elderly individual.[4]

Locomotion is one of the actions most frequently performed by humans throughout their life cycle. Every day, the human musculoskeletal system is challenged to travel across different types and levels of terrain.[5,6] For the elderly, moving from one floor to another is one of the greatest challenges encountered during locomotion, involving as it does the ascent and descent of stairs, which is described as one of the five most difficult tasks performed in old age.[7,8]

Studies have shown that these locations are responsible for the highest rates of falls in this age range.[9] Among the deaths of elderly persons from falls, 10% occur when moving up or down stairs.[10] It is important to note that accidents are three times more common when descending than ascending stairs, with an incidence of 75% and 23%, respectively.[11,12] It has also been noted that accidents that occur when descending stairs result in more serious injuries.[13]

Templer[13] reported that there are moments during the descent of stairs when the risk of a fall occurring is higher, such as: when the swinging leg comes into contact with the next step and the entire body weight is transferred; when a leg loses contact with the ground; and when the swinging foot meets the edge of a step.[13]

The speed with which the lower limb swings in this case can directly influence landing capacity. Greater lower limb displacement speeds, for example, require greater control of the motor system, as increased horizontal speeds can cause a slip of the foot at the moment of contact with the ground. Increased vertical velocities are also connected with greater overburdening of the joints at the moment of contact.[14]

When descending stairs eccentric contractions of the rectus femoris, vastus lateralis, soleus and medial gastrocnemius are performed, acting against the force of gravity. However, it is during the controlled lowering of the stance phase that the eccentric quadriceps activity occurs, aimed at controlling knee flexion and minimizing the impact of the foot against the ground.[15,16]

McFadyen & Winter[15] described the first peak of the vertical force of locomotion as the result of load accommodation, comprising the moment of contact of the foot with the ground until the lowering of the contralateral foot, and the second peak as controlled descent, a phase that lasts approximately from mid-stance to the start of the swing phase.

Although the vertical ground reaction force has two peaks, both on flat floors and when descending stairs, it is important to note that in the latter case the first vertical peak is greater and the second peak lower than when walking on flat floors.[17] The horizontal forces are also different. During descent, the braking impulse is the same as when walking on flat surfaces, but the propulsive thrust is lower.[17,18] These considerations are important for an understanding of the biomechanical differences involved in managing stair descent, demonstrating that the activity involved in walking on flat surfaces and steps are distinctly different tasks and place different demands on the body. In addition, previous studies have shown that climbing stairs is a considerably more demanding task than walking on flat surfaces.[17,19-21]

In old age, climbing stairs becomes a difficult task.[8,22] Larsen et al.[23] evaluated the effect of aging by measuring vertical ground reaction forces (GRF) during staircase activities at different speeds: during ascent at top speed, the

GRF of the elderly studied fell by 28% to 35% in all the stages examined.

As mentioned, motor losses during aging are complex and, although muscle force is the most affected, regardless of walking speed, functional losses result from a variety of factors involved in the aging process.[24] These limitations can lead to the loss of the ability to perform activities of daily living and reduced mobility, which in turn, leads to decreased independence.[25,26] Therefore, the biomechanical analysis of human gait is important as it allows a quantitative measure of mobility to be obtained. Furthermore, it has been established that the risk of falls of the elderly in activities related to ascending and descending stairs is greater than when traveling on flat surfaces. Therefore, the aim of this study was to correlate the vertical ground reaction force and knee angular velocity of young and elderly persons when descending stairs.

METHODOLOGY

The study sample consisted of ten elderly persons aged between 60 and 75, who comprised the Elderly Group (EG), and 16 young women aged between 18 and 25, who formed the Young Group (YG). Both groups performed the stair descent task. The sample size was calculated from the results of the peak knee angular velocity), variable available in literature, with greater standard deviation (14.1) and lower difference to be detected (56°/s), for a two-tailed test with 80% power (1-β =0.80) and α= 0.05, The calculated sample size was nine individuals in each group. Data collection occurred from September 2013 to January 2014.

Those included in YG were healthy volunteers aged 18 to 25 with no history of musculoskeletal injuries in the lower limbs. The EG included volunteers with no known diseases, aged between 60 and 75 years and who displayed normal gait during stair descent. Volunteers who used orthoses to assist walking, reported osteoarticular diseases of the lower limbs, or surgery of any type related to the lower limbs, were excluded from the study.

The present study was approved by the Research Ethics Committee of the Universidade Estadual do Oeste do Paraná, under registration no 111/2013. All participants signed Terms of Free and Informed Consent.

For the study a staircase was built and equipped which allowed the execution of a descent that was as close to normal as possible. The stairs were prepared in accordance with Yu et al.,[21] and consisted of a wooden base, with seven 18 cm high, 28 cm deep, and 1 m wide steps, and a handrail to provide safety for the volunteers. A force plate measuring 46 cm x 49 cm (AMTI OR6-6, USA) was camouflaged by a black rubber pad and fixed in the center of the fourth step of the stairs. There was a free space of two meters in length before the first step and after the last so that the volunteers began and finished the activity with a short walk. These dimensions followed the guidelines proposed by NBR 9077/1993 for the construction of stairs.

An individual identification and assessment form was used to record the data and anthropometric measurements of each participant. This form recorded data such as name, age, gender, height and body mass, knee and ankle diameter and the distance in centimeters (cm) from the anterior superior iliac spine (ASIS) to the medial malleolus.

To determine lower limb dominance the Waterloo inventory was used.[27] This validated test consists of 12 questions that address the use of limbs when performing certain activities of daily living such as kicking a ball, climbing on a chair and killing an insect.

The mechanical variables linked to the movements of body segments were obtained from kinematic data collected by the optoelectronic three-dimensional kinematics system VICON MX (Vicon Motion Systems Inc., Denver, USA) using four infrared Secom Bonita type 10®

cameras with a sampling frequency of 100 Hz and a resolution of 1 MP.

The four cameras recorded the kinematics of 15 reflective markers placed bilaterally on the skin of the participants, which defined the segments involved in the pelvis, legs and feet based on a biomechanical model of 15 segments (Plug-in-Gait SACR, Vicon), which calculates the articulated kinematic from the spatial orientations of the markers (X, Y and Z) and anthropometric measurements of the volunteer. In this way the arrangement of cameras in the data collection area was such that at any time during the task at least two cameras captured each marker when the subject's weight was placed on the stair where the force plate was located.

The motion capture area reflected the capture volume, surrounded by the cameras along the fourth step of the stairs. Calibration allowed the capture volume and the relative position and direction of the camera to be defined. Before kinematic capture was performed dynamic and static calibration of the camera was carried out using a "T" shaped calibration rod pre-defined by the system. During system origin calibration, the rod was placed on a step of the stairs, so marking the origin of the coordinates for the cameras. For the capture volume of each camera errors less than 0.08 mm were accepted.

The force plate was used to acquire the ground reaction force (GRF) kinetic data and for determining when the volunteer touched the step of the stairs. The signals from the force plate were captured on a module of the platform itself with AMTI NetForce software, with a sampling frequency of 100 Hz.

Before beginning actual data collection, the environment and the volunteers were prepared. The environment was controlled in relation to lighting and organization, with the measuring instruments masked. The volunteers wore light exercise clothes to facilitate anthropometric measurements and placement of reflective markers. The reflexive markers were fixed on the following points: sacrum, anterior superior iliac spines, thigh, knee joint line, leg, lateral malleolus, calcaneus and head of the second metatarsal. The markers were placed bilaterally, except for that on the sacrum. Later, the volunteers were asked to practice the stair descent activity to familiarize themselves with the procedure and to ensure that during the descent the volunteers made contact with the force plate with their dominant leg. After this procedure, and once the volunteers were safe and comfortable with the activity they were to carry out, data collection began.

From the highest point of the stairs, the participants performed a short walk to reach the first step, and from there, started to descend continuously, at a self-selected speed and pace, so as to resemble as much as possible a normal activity of daily life. Upon reaching the last step, they continued their movement with a short walk on the ground for at least two meters. The descent was performed until three complete movement cycles were recorded for biomechanical analysis.

The force plate allowed the vertical and horizontal components of the GRF to be determined, allowing the vertical component of the ground reaction force (Fz) in the YG and the EG to be obtained when the foot touched the step. Data from the force plate was processed using AMTI Bioanalysis® software (AMTI, USA). The signals were digitally filtered with a fourth order Butterworth and a 5 Hz low-pass filter and were then normalized by the mass of the individual.

The signals from the kinematics of the stair descent movement were used for three dimensional reconstruction of the biomechanical model and calculation of the angular velocity of the knee joint. The cut-off of the signals was based on the placing of the limb on the force plate. Therefore the analyzed movement sequence represented the period from when the dominant limb passed the non-dominant limb, until the moment when the dominant limb reached the platform on the step immediately below (4th degree), so completely unloading its weight. The reconstruction of kinematic data and the obtaining of angular velocities were performed using the Vicon Nexus® 1.8 software (Vicon Motion Systems Inc, USA) and subsequently exported into text files for the Microsoft Office Excel package®.

Data normality was tested using the Shapiro-Wilk test, and, as values of p= 0.567 and W=0.862 were obtained, a descriptive analysis of the data as mean and standard deviation was performed. The Student's t-test for independent samples was used for inferential analysis and comparisons of angular velocity, knee joint position and peak vertical ground reaction force (Fz). To test for the existence of a correlation between the angular velocity and peak vertical ground reaction force variables, the Pearson correlation test was used. All analysis was conducted using the SPSS v17 statistical package and for all comparisons the significance level α=0.05 was adopted.

RESULTS

The age, body mass and height data of subjects are shown in table 1.

Table 1. Descriptive statistics for age, body mass and height. Cascavel, PR, 2014.

Group	Variables	Mean	sd
YG	Age	21.52	1.09
	Body Mass (kg)	60.22	7.61
	Height (m)	1.64	0.03
EG	Age	66.83	4.34
	Body Mass (kg)	66.69	9.76
	Height (m)	1.59	0.03

YG= young group; EG= elderly group sd= standard-deviation; kg= kilograms; m= meters.

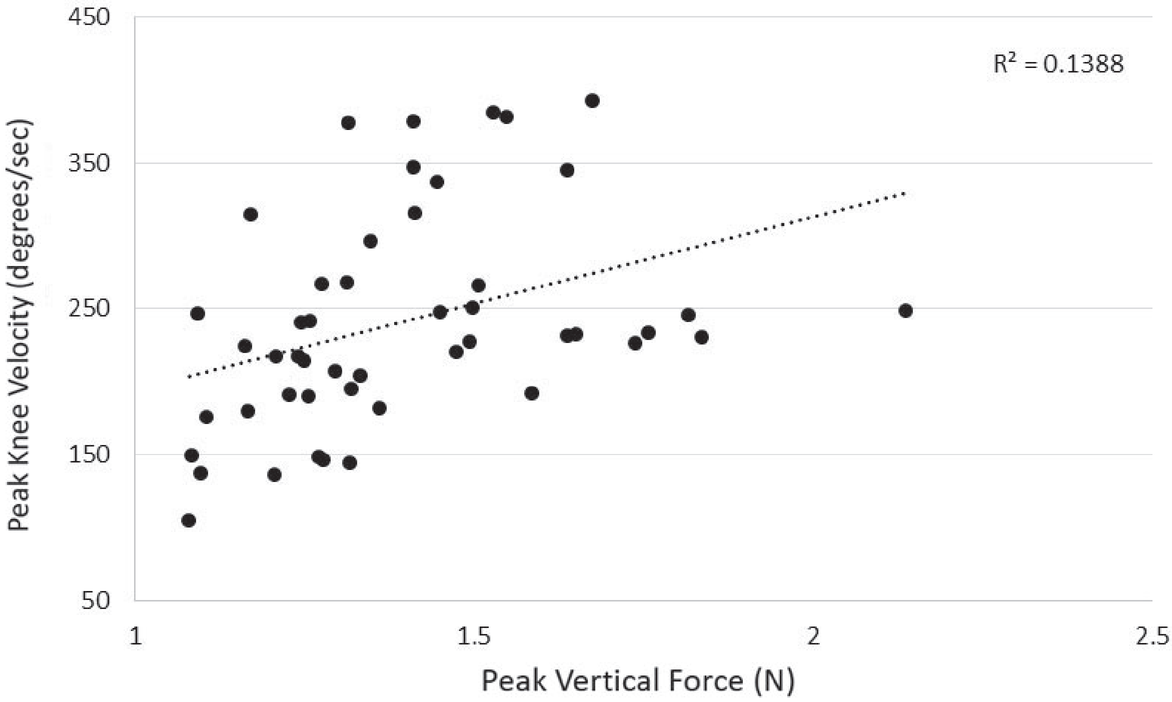
The descriptive and comparative results of the variables of interest are shown in Table 2. It can be seen that there was a difference between the groups (p= 0.02) in relation to peak angular speed, with the YG having a higher average speed than the EG. Furthermore, the position of the knee joint position was more flexed at the time peak angular velocity was reached during stair descent in the EG than in the YG (Table 2). In terms of normalized vertical force (Fz), the YG had greater magnitude of force (1.39), than the EG (1.15), with a significant difference between the two groups (p=0.00).

Table 2. Descriptive and comparative data of variables. Cascavel, PR, 2014.

Variables	Group	Sample	Mean	sd	*p*
PeakVel (g/s)	YG	16	240.72	10.50	0.02*
	EG	10	186.47	13.20	
KneJoiPos (º)	YG	16	59.51	1.86	0.00*
	EG	10	70.81	1.96	
PeakFz (%)	YG	16	1.39	0.03	0.00*
	EG	10	1.15	0.02	

YG= young group; EG= elderly group; PeakVel (g/s) = peak angular velocity in degrees/second; KneJoiPos (º) = knee joint position in degrees; PeakFz (%) = first vertical ground reaction force peak normalized by the body mass of each subject; sd = standard deviation; *p*= significance value; *significant differences found ($p<0.05$).

The result of the Pearson correlation test was statistically significant ($p = 0.000$), with a positive correlation ($r=0.4$) (Figure 1), showing that there was a direct correlation between the angular velocity and the vertical ground reaction force of the volunteers at the moment when the foot touched the lower step of the stairs.



The dashed line represents the projection of the linear regression of the sample, showing the positive correlation between variables.

Figure 1. Correlation between peak angular knee velocity and vertical ground reaction force on a step during stair descent. Cascavel, PR, 2014.

DISCUSSION

Stair locomotion places great musculoskeletal and cardiovascular demands on the individual, as well as requiring information from the proprioceptive, visual and vestibular systems during the various stages of the activity. Aging generates musculoskeletal decline and deficiencies in the sensory system, resulting in impairment of force generation capacity and muscular power.[10] As a result, the task of stair descent becomes proportionally more difficult for this population.[28]

In the present study, the results obtained showed that the peak angular velocity of the knees of elderly persons was lower than younger individuals. In a similar study, De Carli[29] analyzed the stair descent of two different elderly groups, and no differences were observed in the spatiotemporal parameters of gait, making it clear that the age difference in the sample of the present study was probably the determining factor for the different findings between the groups.

A greater ability to produce muscle force and strength can influence balance capacity[16] and change speed of movement on stairs. As changes experienced during aging reduce such abilities in this population, this may explain the fact that the elderly persons had a lower peak speed. Larsen et al.[30] conducted a 12-week strength training program with 23 elderly persons and detected improvements in muscle strength and the loading and unloading of weight, which were associated with an increase in stair climbing speed. In addition, increases in speed and decreases in ascent time have been associated with a decreased risk of falls when moving over obstacles.[30] This result suggests that strength training can be a key to the reduction of falls on stairs among the elderly, both when ascending and descending.

The kinematics of the knee joint position when descending the stairs were significantly different between the groups, with the EG displaying a more pronounced pattern of knee flexion during the task. Other studies related to young and elderly persons descending stairs found similar results related to the ability to meet the demands of this task.[31-33] However, the elderly persons operated proportionally very close to their maximum joint amplitudes compared to the young people, which makes descending stairs conducive to falls.[32,33]

With respect to peak vertical ground reaction force, literature provides evidence contrary to the results found in the present study, reporting that increased age does not affect the magnitude of GRF exercised during stair descent. Unlike climbing, descending stairs is characterized by predominantly eccentric contractions of the muscles of the lower limbs in order to reduce flexor torques.[33] With advancing age there is less reduction in eccentric force compared to concentric force. While approximately nine newtons of eccentric force are lost per decade, reductions in concentric force are about 30 newtons per decade.[31] This evidence has been proven in a study by Reeves et al.,[33] in which similar GRF results were found for young and elderly individuals. A study by Christina & Cavanagh,[17] did not find differences in GRF when descending stairs, other than a reduction in the second horizontal force peak, which had a more conservative profile among elderly persons.

However, the present study found a difference between groups, with the elderly persons displaying lower peak vertical force. One hypothesis for this finding would be that elderly persons have a more cautious gait as a compensatory strategy to the changes resulting from the aging process. Another hypothesis is that ground reaction forces are dependent on speed.[17] The study showed that the angular velocity of the elderly persons was lower than that of the young people, which could also explain the lower peak vertical ground reaction force at the time of support.

The results also showed that there was a positive correlation between knee angular velocity and vertical ground reaction force, indicating that higher angular velocities were associated with higher ground reaction forces in both groups. A study by De Carli[29] found lower ground reaction forces were associated with lower angular displacement velocity. Despite the fact that this finding was related to ascending stairs, it supports the results related to stair descent obtained in the present study.

A limitation of the present study that was revealed during analysis was the fact that only a force plate was used, which did not allow the analysis of the complete cycle of a step when descending stairs, unlike the study by De Carli.[29] Another limitation was the gait speed during the descent of the elder individuals. As the descent speed for each volunteer was not pre-determined and the speed was self-selected by volunteers, these findings were subject to intrapersonal variability. If a system that controls speed had been employed, changing the physiological pattern, the susceptibility of the elderly persons to falls would increase significantly.

In closing, the present study revealed differences between young and elderly individuals, and raises the possibility of using the methods described herein for the biomechanical characterization (kinetics and kinematics) of stair descent to structure training programs focused on the deficiencies identified, in order to reduce the risk of falls during the course of this activity, which is extremely common in daily life.

CONCLUSION

Based on the results of the present study, it can be concluded that the peak knee angular velocity of elderly people is lower than that of young people during the swing phase of stair descent, an activity during which the risk of falls among the elderly population is high. Elderly persons also displayed lower vertical ground reaction force in the stance phase, and the fact that these two associated variables correlated positively indicates that the greater the angular velocity, the greater the ground reaction force.

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