RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DOI: http://dx.doi.org/10.5007/1980-0037.2014v16n1p66

original article

Kinetic analysis of floor-to-stair transition gait of elderly with different functional levels

Análise cinética da marcha de idosos com diferentes níveis de funcionalidade na transição entre o terreno plano e a escada

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Abstract – Climbing stairs represents a difficult and dangerous task for the elderly, and its performance depends on the functional ability level of the subject. The aim of this study was to compare the kinetic parameters of the floor-to-stair transition gait of elderly with different levels of functionality. The sample comprised 34 subjects, divided into two groups through Cluster techniques according to the results of functional tests (Timed Up & Go and sit-to-stand test), with G1 being the group with lower functionality (n=13, 72.61 ± 0.28 years) and G2 the group with greater functionality (n=21, 69.14 ± 4.96 years). Ground reaction force (GRF) data was captured with one AMTI force plate at a frequency of 1000 Hz, placed over the first step of a stairs with 4 steps (17.5 cm high x 29 cm wide and 31° slope). Descriptive statistics and Mann-Whitney test were used for data analysis ($p \leq 0.05$). G2 presented higher vertical GRF and lower support time in the ascending phase ($p \leq 0.05$). There were practically no differences in GRF values between groups in the descending phase. Based on these findings, we concluded that GRFs are influenced by subject's functional ability level and can influence the risk of falls during stair ascent.

Key words: Elderly; Functionality; Gait; Movement; Stairs

Resumo – *Transpor escadas representa uma tarefa difícil e perigosa para os idosos e apresenta alto risco de quedas. O nível de funcionalidade do idoso é um fator determinante para sua independência e segurança na transposição de terrenos. Assim, o objetivo deste estudo foi comparar os parâmetros cinéticos da marcha de idosos com diferentes níveis de funcionalidade na transição entre o terreno plano e a escada na subida e na descida. Participaram do estudo 34 idosos, divididos em dois grupos pela técnica de Cluster de acordo com os resultados obtidos nos testes funcionais aplicados (Timed Up & Go e Teste de sentar e levantar), sendo o G1 o grupo com menor funcionalidade (n=13, 72.61 ± 0.28 anos) e o G2 o grupo com maior funcionalidade (n=21, 69.14 ± 4.96 anos). A captura de dados de força de reação do solo (FRS) foi feita através de uma plataforma de força AMTI a 1000 Hz, acoplada no primeiro degrau de uma escada com 4 degraus (17,5 cm altura x 29 cm largura e 31° de inclinação). Para análise dos resultados, utilizaram-se a estatística descritiva e o teste de Mann-Whitney (p≤0.05). Na subida, maiores forças verticais e menor tempo de apoio foram encontrados no G2 (p≤0.05). Os grupos praticamente não revelaram diferenças nas aplicações de força no solo na descida da escada. Baseado nos resultados encontrados, é possível concluir que as FRS são influenciadas pelo nível de funcionalidade do idoso na subida da escada.*

Palavras-chave: *Escada; Idosos; Funcionalidade; Marcha; Movimento.*

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Received: 28 February 2013
Accepted: 20 June 2013

INTRODUCTION

Epidemiological reports on falls indicate that 50% of falls occur during locomotion, as differences in the path impose challenges such as deviating from obstacles and changing direction and step length[1]. Stair locomotion has been described as one of the most challenging and dangerous task in the daily life of the elderly and is one of the main places for the occurrence of trips and falls[2,3], which constitute approximately 10% of fatal accidents in the aged population[3]. Specifically, the first and last two steps of the stair, considered as a transition to the floor, represent the places with the highest incidence of accidents (70%)[2,4], due to the need of performing biomechanical adjustments to progress between levels[5]. These adjustments are influenced by the state of the sensorial, central nervous and muscular systems, which depend on degenerative processes that compromise the ability of the elderly to generate force and power[6] and, consequently, on their functional level[7].

The functional capacity of the elderly is an important parameter that reflects the independence to perform daily activities and the risk of falls[8]. Currently, there are numerous tests applied to identify older adults with lower and greater functional capabilities and studies devoted to relate the results of these tests to the level of dynamic balance, agility and power. These capabilities have been considered as essential to ascend and descend stairs safely[9-11]. Physically fitter elderly people, i.e., with better functionality, are less prone to falls[12] and probably differ in the strategies applied to take stairs. However, these strategies have not been described in the literature.

The aim of this study was to compare kinetic parameters between two groups with different functional levels in the transition between floor and stairs during the ascending and descending phases.

METHODOLOGICAL PROCEDURES

Participants

Thirty four elderly of both sexes (4 males and 30 females) engaged in a community project offered by the Federal University of Paraná (UFPR) and designed to promote general physical activities (twice a week) were selected to participate in the study. The elderly invited to participate in the study voluntarily attended a scheduled meeting at the Center for Motor Behaviour Studies. The inclusion criteria considered the ability to ascend and descend stairs without external assistance and with alternating feet. Based on the results of functional tests, the technique of k-means cluster approach was applied to divide the elderly into two groups: a group with low functional level (G1) and a group with high functional level (G2) ($p<0.001$), with characteristics as described in Table 1. Subjects were informed about the objectives and risks of the study and signed an informed consent form. The project was approved by the university's Research Ethics Committee under the approval number 156 533.

Table 1. Anthropometric and functional characteristics of the subjects.

Variables	G1 (n=13)	G2 (n=21)
Age (years)	72.61 ± 0.28	69.14 ± 4.96
Height (m)	1.57 ± 0.07	1.56 ± 0.07
Mass (kg)	71.05 ± 9.80	63.5 ± 8.90
BMI (kg/m^2)	28.75 ± 3.61	25.99 ± 2.83
TUG (s)	7.69 ± 0.92	6.7 ± 0.71
FTSS (s)	10.44 ± 1.32	7.55 ± 0.87

NOTE: TUG - Timed Up and Go test; FTSS - Five Times Sit-to-Stand test

Instruments

The functionality of the elderly was assessed by the Timed Up and Go test (TUG)[13] and the Five Times Sit-to-Stand test (FTSS)[14]. The TUG consists of rising from a chair, walking a 3-m distance, turning around through the same route to the sitting position as fast as possible. In the FTSS test, the subject must sit and rise from a chair five times as fast as possible with the arms crossed over the chest. In both tests two attempts were performed, but only the one with the shortest time was used for the purpose of the study.

Kinetic data was acquired in a wooden stairs of four steps of 17.5 cm high, 29 cm wide, and an angle of 31° of inclination that ended with a plateau of 49 cm wide, according to the NBR 9050, established by the Brazilian Association of Technical Standards. To determine the ground reaction forces (GRF) on the ascending and descending phases, an AMTI force platform model OR6-7-2000 operating at 1000 Hz was embedded in the first step of the stairs (Figure 1). The force platform was covered with a rubber material identical to that used in the other steps and the walkway in order to avoid the subject to alter their gait pattern due to the presence of the equipment.

Data acquisition

After performing the functional tests, the elderly were familiarized with the data collection conditions and were asked to walk up and down the steps freely. For the sake of safety, subjects wore a safety harness attached to a system of pulleys fixed on the ceiling that was operated by a researcher to control the rope according to the progression of the subject through the steps. The harness, the carabiner and the rope ensured experimental safety (Figure 1).

During data collection, subjects were instructed to walk up and down the steps alternating feet and to have a 5-second break at the top of the stairs in order to allow the researchers to differentiate between ascending and descending phases. Data from 10 trials were acquired, but they were considered valid only when the left foot was in contact with the force plate.

Data processing

The GRF data were filtered using a 4th-order low-pass Butterworth filter with a cutoff frequency of 10Hz in order to smooth the force-time curves and eliminate the interfering noise caused by the vibration of the stair structure. For analysis purposes, one ascending and one descending cycle were selected. A qualitative approach was applied from the 10^{th} trial on. GRFs were normalized by subjects' body weight (BW). One subject was excluded at the descending phase due to software issues during data collection.

Definition of GRF parameters

The following variables were selected: double support time (TA – s), first vertical force peak (Fz1 - BW), second vertical force peak (Fz2 - BW), first anterior-posterior force peak (Fy1 - BW), second anterior-posterior force peak (Fy2 - BW), vertical loading rate (TXFz1 - BW/s), vertical unloading rate (TXFz2 - BW/s), vertical impulse (IFz - BW.s), anterior-posterior breaking impulse (IFy1 - BW.s), anterior-posterior propulsive impulse (IFy2 - BW.s) and the resultant impulse (IRFzy - BW.s). The selected variables are represented in the force-time curve shown in Figure 2.

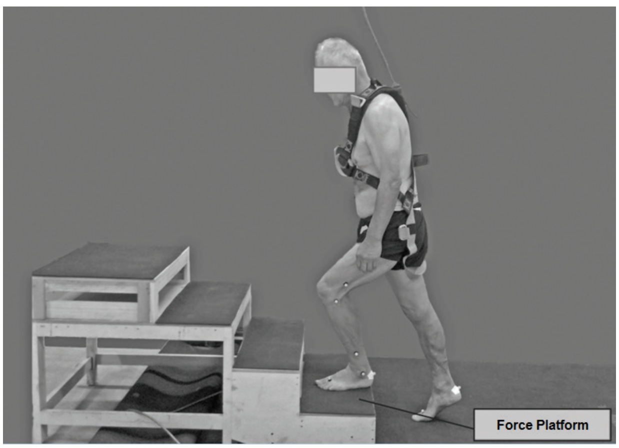

Figure 1. Position of the force platform in the stairs and a participant using the safety harness.

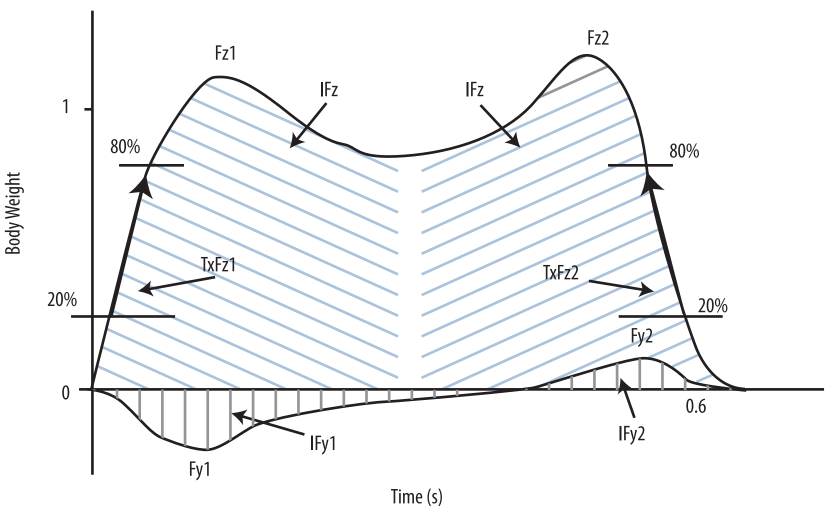

Figure 2. Ground reaction force parameters.

In the vertical direction (Fz), the force magnitude was divided into two equal parts and peaks were determined by the highest value found in each part[15,16]. Rates of loading and unloading force were calculated according to the formula:

$$\text{Rate} = \Delta\ \text{force} / \Delta\ \text{time}$$

These rates of force development were used to describe force development speed, when force was applied in the moment when the foot touched the ground (loading) and in the moment when the foot left the ground (unloading)[15]. In the present study, force variation was defined between 20-80% of the Fz1 and from 80-20% of Fz2, which were considered as the most linear parts of the curve.

Vertical and horizontal impulses (breaking and propelling) were determined by calculating the integral of the force-time curve. To differentiate the breaking from the propelling impulse, the anterior-posterior curve was divided into two parts using the moment when the curve is equal to zero as a criterion. This variable was calculated only for the ascending phase and represents the amount of force produced to push the subject forward and upward. The anterior-posterior peaks were determined using the division applied to calculate impulse. Peak forces represent the greatest value in each region of the force-time curve.

Statistical Analysis

The Shapiro-Wilk test did not confirm data normality and revealed the need of a non-parametric approach. Descriptive statistics of median, mean and standard deviation was applied to characterize the kinetic variables of both groups. The Mann-Whitney "U" test was applied to compare the independent variables between the groups. The significance level was set at $p \leq 0.05$ in all tests, which were performed using the software Statistica version 7.0 (StatSoft, Tulsa, USA).

RESULTS

With the data captured from the force platform it was possible to determine the duration of support time, which revealed differences only during the ascending phase. The support times of the groups were 0.99 ± 0.19s (G1) and 0.77 ± 0.13s (G2) in the ascending phase (p=0.00), and 0.79 ± 0.17s (G1) and 0.70 ± 0.09s (G2) in the descending phase (p=0.11).

In the ascending phase, it was noticed that the most significant differences occurred in G2, except for resultant impulse. The vertical and resultant impulses of the less functional group (G1) were 20.6% and 22.9% higher than those of the group with greater functionality, respectively.

The loading and unloading rates of the group with greater functionality (G2) were, respectively, 26.6% and 42.0% higher when compared to the group with lower functionality (G1) (Table 2). The results in the descending phase are presented in Table 2. A great similarity was observed between the groups with different functional levels, and it was possible to identify differences only in unloading rate (p=0.01) and anterior-posterior peak force (p=0.03).

Table 2. Kinetic parameters during ascending and descending phases in groups of elderly with lower (G1) and greater (G2) functional levels.

Variables	Ascending		p	Descending		p
	G1 (n=13)	G2 (n=21)		G1 (n=12)	G2 (n=21)	
	Median	Median		Median	Median	
Fz1 (BW)	0.97	1.00	0.28	1.39	1.34	0.70
Fz2 (BW)	1.08	1.16	0.00*	0.88	0.93	0.20
TXFz1 (BW/s)	3.84	5.73	0.02*	12.10	11.9	0.70
TXFz2 (BW/s)	9.42	11.73	0.00*	7.53	8.20	0.01*
Fy1 (BW)	0.10	0.12	0.29	0.09	0.09	0.62
Fy2 (BW)	0.05	0.05	0.48	0.19	0.22	0.03*
IFy1 (BW.s)	0.03	0.03	0.21	0.01	0.01	0.35
IFy2 (BW.s)	0.01	0.01	0.12	0.04	0.05	0.99
IFz (BW.s)	0.82	0.6	0.03*	-	-	-
IRFzy (BW.s)	0.81	0.6	0.00*	-	-	-

NOTE: first vertical force peak (Fz1 - BW), second vertical force peak (Fz2 - BW), first anterior-posterior force peak (Fy1 - BW), second anterior-posterior force peak (Fy2 - BW), vertical loading rate (TXFz1 - BW/s), vertical unloading rate (TXFz2 - BW/s), vertical impulse (IFz - BW.s), anterior-posterior breaking impulse (IFy1 - BW.s), anterior-posterior propulsive impulse (IFy2 - BW.s), resultant impulse (IRFzy - BW.s).
* Significance level at $p \leq 0.05$.

At the descending phase, 3 elderly presented a different pattern in the vertical force curve in which a clear identification of the second force peak was not possible. Thus, the data for Fz2 and TXFz2 of these participants were not included (two subjects from G2 and one subject from G1).

DISCUSSION

The main finding of this study was that elderly with greater functionality differed from those with lower functional levels at the ascending phase, revealing higher peak force and rate of force development. In addition, most studies in the literature have assessed kinetic aspects during the stationary or ascending phases and disregarded transition between plane surfaces, which was the condition analyzed in the present work, since it is when most accidents occur. For a better understanding of the results, the discussion section was organized to allow separate comparisons of the kinetic parameters between groups during the ascending and descending phases.

Ascending phase

During the transition from the floor to the first step, the elderly with lower functional levels presented lower peak force and rates of loading and unloading forces, as well as higher impulses. The modulation of GRF magnitude is related to the way the interaction with the environment occurs, i.e., how forces applied by the lower limb are transmitted to the ground, and depends on the subject's ability to produce tension. Thus, the reduction of muscle strength that is generally present in response to the ageing process may result in decreased capacity to generate joint torques to climb stairs[17].

Differences in peak force and in the rate of force development between elderly with greater and lower functionality may be explained by the greater muscle power of the group with greater functionality. Producing sufficient force and power around the ankle and knee joints is mandatory to the ascending phase performance, which is necessary to move on plane surfaces safely[11,18-21]. Thus, elderly with greater functionality (G2) are likely to show higher capacity to generate strength and power and, consequently, better ability to walk on plane surfaces and stairs.

The magnitude of the impulse to raise the center of mass is related to the duration of the support (stance phase). The greater support time observed in the group with lower functionality may be interpreted as a compensatory strategy to increase the vertical impulse. The greater vertical impulses and, consequently, resultant impulses found in the group with lower functionality (G1) suggest a greater energy demand than that of the more functional group (G2). The muscle forces required during the support phase and the time available to develop these forces are determinants of the amount of energy expended in the movement[22]. Heise and Martin[23] performed a study with runners and demonstrated an inverse correlation between vertical impulse and running performance. Thus, less economic runners generate greater impulses that demand greater muscle fiber recruitment[23]. These arguments are in agreement with Larsen et al.[16], who concluded that ageing is reflected by a reduction in the functional reserve, i.e., the elderly climb stairs using a greater percentage of their maximal capacity to generate forces, which reduces the force reserve available. This reduction may result in muscle fatigue and a worse postural control during stair ascent, which is also suggestive of greater risk of falls[16].

The group with greater functionality showed shorter support times and greater vertical force peaks that resulted in higher loading and unloading rates. The augmented rates indicated a greater intensity in weight transfer, as a response to the better capacity of the group with greater functionality to apply forces in a short time, which is suggestive of smaller joint stiffness[25] however, there are no reports on slip resistance requirements for stair descent.

Descending phase

At the descending phase no significant differences between groups were found, except for the rate of unloading force and the second horizontal peak force. Perhaps the functionality level may not be a limiting factor for the descending phase. However, the descending phase is a task deemed as being 3 times more dangerous than the ascending phase[2] and represents a challenging task for the elderly.

There is evidence that ageing does not influence GRF values during the descending phase[26]. Differently from the ascending phase, descending is predominantly characterized by eccentric muscle contractions of the lower limbs to reduce the torque produced by the flexor muscles[26]. As age advances, there is a smaller reduction of the eccentric strength when compared to the concentric strength. The decrease in eccentric forces is of approximately 9N per decade, while the reduction in concentric forces is of approximately 30N for the same period of time[27]. The purpose of this study was to examine the influence of aging on three expressions of muscle strength (isometric, concentric, and eccentric. Thus, muscle strength does not seem to constitute a highly limiting factor during the descending phase[15,25,28]". Reeves et al.[26] reported similar GRF values in elderly and young subjects, but detected different joint moments when the elderly achieved higher peaks that were close to their maximal capacities, which may have turned the task challenging.

Differences in unloading rates and in the second anterior-posterior peak force revealed a more vigorous takeoff of the foot in the group with greater functionality. These two variables occur during the pre-swing phase, which is characterized by generating propulsive forces. The greater capacity to control the center of mass suggests a better postural control or a reduced stiffness around the ankle of the elderly with greater functional capacity and a better safety in the descending phase[25]however. Subjects with low functional capacity may move on plane surfaces less safely[29]. Therefore, the group with lower functional capacity may have reduced the propulsive forces due to their lower ability to generate torque around the ankle joint, which consequently decreased safety during the performance of the task. It is likely that this may be a more conservative and cautious strategy applied to better control the descending phase[25].

The movements performed during the task, especially in the descending phase, with a reduced number of steps, may not correspond to the conditions found in real life, where the number of steps is greater. Although subjects were secured by the harness, the absence of a handrail may have led them to perceive the task as unsecure, which may have influenced the results. The present analysis was performed in physically active subjects, and the responses in sedentary or less physically active subjects may result in larger discrepancies.

CONCLUSION

Functionality level is an important factor related to mobility in the elderly, which influences the ability to climb stairs. In contrast to the initial hypothesis, the descending phase did not show differences in GRF between groups, indicating that functionality is not a limiting factor for the descending phase.

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