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Abstract— **Kinematic and electromyographic analyses of gait of gait require the attachment of markers and skin electrodes on the subjects, making them time-consuming procedures. The evaluation of force-time curves from ground reaction forces allows for immediate visual inspection of trials and is a relatively simple method that obtains the magnitudes of these forces imposed on the human body during the gait cycle. Twenty-five children and thirty-three elderly women performed five walking trials each, at a self-selected pace, while wearing sports footwear, on a 6.0 m long by a 1.4 m wide walkway with 8 embedded force platforms. Elderly women walked slower than children, with longer stance phase duration, increased step rate, and shorter stride length. Future efforts should focus on validating these results with kinematic data and should consider including a group of young adults for comparison.**

Keywords—aging, kinetics, biomechanics.

I. INTRODUCTION

Kinematic analysis and electromyographic measurements of gait require the attachment of markers and surface electrodes on the subjects, making them time-consuming procedures. On the other hand, the evaluation of force-time curves from ground reaction forces (GRF) allows for immediate visual inspection of trials and is a relatively simple method that obtains the magnitudes of the reaction forces imposed on the human body during the gait cycle. Also, other variables can be calculated from the GRF curves, such as the impulses in the individual subphases of the gait stance phase [1]. These GRF components provide a comprehensive interpretation of how the forces act on the body, moving across the supporting foot, and causing the movement during walking. They have been successfully used to evaluate normal and pathological gait patterns in healthy children [2], healthy older adults [3], children with flatfoot deformity [4], deaf children [5], obese children [6], children with autism spectrum disorders [7], older adults with neuropathic gait [8], and older adults with Parkinson's disease [9].

Currently, knowledge about the differences between children and older adults' gait is limited. Several studies have described age-related differences in gait kinetics and kinematics [3], [10–13]. However, they have not identified the nature and the extent of gait differences or impairments that should be expected as a natural process of aging, and which of them can be a result of pathological conditions affecting the aged motor system. Moreover, few of these studies have focused on the causes of impaired gait in the elderly [3], [12], [13] and most of the scientific publications can be characterized as attempts to describe age-related differences in temporal and kinematic walking parameters [13]. Specifically, in relation to force production in children and in older adults, there seems to be no consensus on the differences that may occur during the stance phase. Therefore, the purpose of this study was to compare the GRF during the gait and its derived parameters between children and older women.

II. MATERIAL AND METHODS

A. Subjects

Twenty-five children (age 6.39±1.88 years) and thirty-three elderly women (age 70.48±6.66 years) took part in this study. A non-probability sampling process of intentional type was performed, in which subjects were selected through a direct approach, excluding those individuals who presented a history of neuromusculoskeletal injuries and/or have been submitted to an orthopedic/neurological surgery in the last two years.

B. Procedures

Each participant performed five trials following a verbal cue, at a self-selected pace, while wearing sports footwear, on a 6.0 m long by a 1.4 m wide walkway with 8 embedded force platforms (BTS Bioengineering). The subjects stepped with one foot on each force platform. In the trials in which they were unable to do so, data were discarded. The GRF sampling rate was of 1000 Hz. The signal was in-line low-pass filtered at 795Hz. This is a hardware filter that comes builted-in the BTS force platforms. Data were exported in text format containing the triaxial forces (y: anterior-posterior; x: mediolateral; z: vertical). The mediolateral forces were not included in this study due to their greater variability and low reliability.

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A routine was developed on the software Octave 4.4.1 to calculate the following parameters: mean vertical force (Fz) and mean anterior-posterior force (Fy). The algorithm first normalized the data by body weight and then measured the parameters of interest. It then measured the loading response peak (F1), midstance valley (F2), and terminal stance peak (F3). Then, it calculated the area under the curve to measure the impulse of loading response and midstance (I1), impulse of terminal stance and pre-swing (I2), as well as the total impulse of the vertical GRF (I3). After this process, the algorithm determined the times related to the force events, time to F1 (T1), time to F2 (T2), time to F3 (T3) and time to braking peak phase (T4). In addition to the variables related to the vertical component of GRF, the routine calculated the variables related to the anteroposterior component of GRF, such as braking peak (F4), propulsive peak (F5), duration of the braking phase (T5).

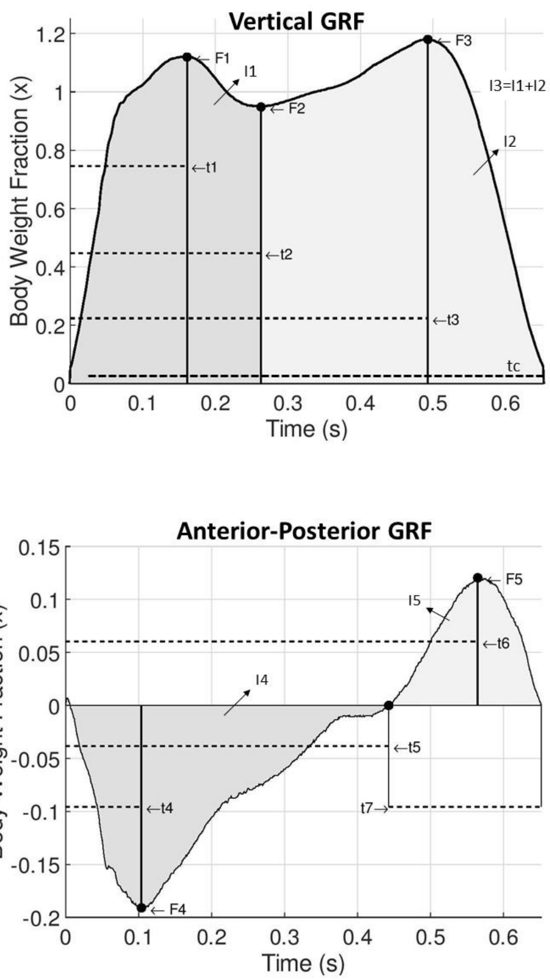

Fig. 1. Vertical and Anterior-posterior (GRF) profiles, normalized by body weight during the stance phase. (Top) Fz (vertical): F1=loading response peak; t1=time to F1; F2= midstance valley; t2=time to F2; F3= terminal stance peak; t3=time to F3; tc=duration of stance phase; I1= impulse of load response and midstance; I2= impulse of terminal stance and preswing; I3=total impulse of the vertical GRF. (Bottom) Fy (anterior-posterior): F4=braking peak; t4=time to F4; F5=propulsive peak; t5= duration of braking phase; t6=time to F5; t7=time of propulsive phase; I4=braking impulse; I5=propulsive impulse.

Statistical analysis of the parameters was performed in SPSS v.21.0. Student's *t*-tests were used to compare gait parameters between children and older adults. Level of significance was set a priori at $\alpha = 0.05$. All tests were two-tailed. Cohen's *d* measurements of effect size are provided when appropriate.

III. Results

A. Statistics

Descriptive analyses showed that F1, F2, F3, F4, F5, I4, I5, I6, TC, T2, T3, T4, and T5 were not normally distributed. Normality was tested by dividing *Skewness/SE Skewness*, and *Kurtosis/SE Kurtosis*, with a critical *z*-value of 0.05. Mann-Whitney tests were used to confirm the level of significance in those cases. There were no changes in statistical significance for F1, F4, F5, TC, T1, T2, T3, T4, T5, I1, I2, (all $p < 0.001$), and F2 ($p = 0.002$). Antero-posterior impulses remained statistically nonsignificant, I4 ($p = 0.245$), and I5 ($p = 0.272$), while F3 ($p = 0.036$), and I5 ($p < 0.001$) mean differences were statistically significant.

B. Ground reaction forces: vertical parameters

The results for vertical GRF are summarized on Table 1. Elderly women had lower loading response peak (F1) when compared to children. However, midstance valley (F2) was greater in the elderly when compared to children. There were no differences in terminal peak stance (F3) between the elderly and children.

The total stance phase duration (TC) was greater in the elderly than in the children. Time to loading response (T1) was also greater in the elderly than in children. Likewise, time to midstance valley (T2) was greater in the elderly when compared to children, and the time to terminal stance peak (T3) was also greater in the elderly compared to children.

The area under the curve showed that the impulse of loading response and midstance (I1) was greater in the elderly than in children. The impulse of terminal stance and pre-swing (I2) was greater in the elderly when compared to children. Consequently, the impulse of the vertical GRF (I3) was greater in the elderly than in children.

Table 1. Summary of GRF Vertical Parameters

Par.	Gr.	*M*	*SD*	*df*	*t*	*p*	*d*
F1	EW	0.982	0.091	29.49	-3.30	0.002	0.91
	C	1.146	0.234				
F2	EW	0.813	0.101	56	3.07	0.003	0.01
	C	0.717	0.135				
F3	EW	1.028	0.079	56	-1.57	0.122†	
	C	1.092	0.215				
TC	EW	0.730	0.079	56	10.93	<0.001	3.37
	C	0.516	0.064				
T1	EW	0.210	0.046	56	8.71	<0.001	2.82
	C	0.116	0.031				
T2	EW	0.360	0.065	56	7.74	<0.001	2.52
	C	0.247	0.036				
T3	EW	0.545	0.052	56	8.71	<0.001	3.09
	C	0.400	0.047				
I1	EW	0.264	0.034	56	4.89	<0.001	1.14
	C	0.210	0.048				
I2	EW	0.288	0.038	56	5.99	<0.001	1.69
	C	0.218	0.050				
I3	EW	0.552	0.059	56	6.13	<0.001	1.78
	C	0.429	0.092				

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Note. Par. = Parameters; Gr. = Group; *M* = mean; *SD* = standard deviation; *df* = degrees of freedom; *d* = Cohen's *d*. † = Mann-Whitney significant.

C. Ground reaction forces: antero-posterior parameters

The results for antero-posterior GRF are summarized on Table 2. Regarding the antero-posterior parameters of GRF, the braking peak (F4) was smaller in the elderly when compared to children. Similarly, the propulsive peak (F5) was smaller in the elderly when compared to children. Time to braking peak phase (T4) was smaller in the elderly when compared to children. There were no differences between groups in braking impulse (I4) and propulsive impulse (I5).

Table 2. Summary of GRF Antero-posterior Parameters

Par.	Gr.	*M*	*SD*	*df*	*t*	*p*	*d*
F4	EW	0.116	0.033	56	-4.63	<0.001	1.26
	C	0.179	0.068				
F5	EW	0.126	0.031	34.13	-3.69	0.001	1.21
	C	0.175	0.059				
T4	EW	0.123	0.025	30.90	-26.42	<0.001	8.66
	C	0.457	0.059				
I4	EW	0.021	0.004	56	0.63	0.525†	
	C	0.020	0.007				
I5	EW	0.020	0.004	56	0.70	0.775	
	C	0.020	0.007				

Note. Par. = Parameters; Gr. = Group; *M* = mean; *SD* = standard deviation; *df* = degrees of freedom; *d* = Cohen's *d*. † = Mann-Whitney significant.

IV. Discussion

Ground reaction forces are a valuable time-saving tool in the gait analysis. To the best of our knowledge, there was a paucity of data on the different kinetic parameters of normal gait in elderly women when compared to children. Overall, we have found that children and elderly women presented different vertical and anterior-posterior GRF parameters, time, and impulses during all phases of the gait, except for terminal peak vertical force, and anterior-posterior breaking and propulsive impulses.

More specifically, regarding vertical GRF parameters, time and impulse, our results showed that elderly women had a lower loading phase (F1), greater midstance phase (F2), and a similar terminal peak stance (F3) forces when compared to children. In terms of time, the total stance duration (TC), loading response (T1), midstance (T2), and terminal stance peak (T3) were greater in elderly women than in children. Likewise, the loading response and midstance (I1), terminal stance and pre-swing (I2), and total impulse (I3) were greater in elderly women. Regarding the antero-posterior parameters, elderly women had a smaller braking peak force (F4), propulsive peak force (F5), and time to braking peak phase (T4). Elderly women and children did not differ in terms of braking (I4) and propulsive (I5) impulses.

In terms of vertical GRF, the loading response peak is positively correlated with walking speed and stride length [14]. Since elderly women had a lower loading response peak, it appears that they have taken shorter steps and/or walked with lower speed. The elderly's relatively higher midstance valley also indicates that they have had higher loading during midstance, which is also associated with shorter stride length and lower walking speed. Wu *et al.* [15] have associated the lower midstance valley with the occurrence of gastrocnemius inflexibility, with postural rigidity being a common stabilization strategy in older adults [16]. The groups had no difference in terminal peak stance relative vertical force, which was unexpected. Generally, terminal peak stance magnitude is positively correlated with walking speed. Hence, we would expect that children would present a greater F3. It is possible that statistical significance supporting this hypothesis was not achieved due to the greater variability (*SD*) in children's F3. Nonetheless, the greater walking speed presented by children when compared to elderly women is supported by the higher braking and propulsive peaks in the antero-posterior directions. Lastly, the similar braking and propulsive impulses, coupled with the lower antero-posterior GRF in elderly and higher antero-posterior GRF in children, further supports the hypothesis the elderly spent more time in their whole stance phase (i.e., more time in contact with the ground), while taking shorter steps, and children spent less time in their stance phase (i.e., less time in contact with the ground), while taking shorter and faster steps.

An increase in total stance time in elderly subjects is a well-known phenomenon that has been hypothesized to occur due to a biomechanical strategy to increase time in contact with the ground, resulting in increased stability [17], [18]. It is associated with a decrease in step length and an increase in step frequency in elderly subjects [18], [19]. The decrease in step length requires an increase in step frequency in order to maintain the same walking speed. On the other hand, children tend adopt an opposite strategy, by increasing stride length instead of step length [20] to attain their desired walking speed. These described strategies adopted by older adults and children support our results in terms of vertical stance timing. Regarding the anterior-posterior time parameters, our results indicate that elderly women had a shorter time to braking peak phase (T4), which is expected to happen when there is a decrease of swing time and an increase of stance time [21]. This is an outcome of the smaller acceleration epochs required to break the movement during loading phase and start the transition toward the midstance.

Elderly women showed greater vertical impulses overall. Since impulse is the amount of force applied over time, taking into consideration the lower loading response peak (F1), greater midstance valley (F2), and similar terminal peak stance (F3) along with overall greater time during all vertical stages of the stance phase (T1, T2, T3), we can infer that the vertical impulses generated by elderly women are due to a greater time in the stance phase [14]. Conversely, children had a greater loading phase peak force (F1) and relatively shorter stance times, resulting in lower impulses, which is indicative of a longer step length and shorter step interval [14].

The results from this study should be interpreted with caution. Several assumptions about gait kinematics are inferred from GRF and supporting literature. Future efforts should focus on validating these inferences with kinematic data. Also, future studies should consider including a group of young adults comparing kinetics parameters walking at different speeds, to test the strategies adopted by each group (children, young adults and older adults) concerning gait spatiotemporal parameters (step length and step frequency).

V. Conclusion

Significant differences in kinetic gait parameters were observed when comparing elderly women and children. Based on GRF, stance phase times, and impulses we have concluded that elderly women walked slower than children, with longer stance phase duration, increased step rate, and shorter stride length. These differences are likely the results of the opposite strategies adopted by each group.

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