10-2002

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BRIEF REPORT

Frequency domain characteristics of ground reaction forces during walking of young and elderly females.

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Acknowledgements

The authors gratefully acknowledge the financial support of the Edward Holt Trust (UK), the Nuffield Foundation (UK) and The Stroke Association (UK).

Abstract

Objective: To examine the frequency domain characteristics of the ground reaction forces of young and elderly females during free walking and walking with a unilaterally added ankle weight.

Design: A two-factor (weight by age) with repeated measures on the weight factor design was used to examine the frequency content of all three components of the ground reaction force..

Background: Frequency domain analysis has the potential to assist in identifying changes in gait that may be masked in the time domain. No research has been done to identify changes in gait due to age-related impairments in the frequency domain.

Methods: Ten young and ten elderly females walked at a prescribed speed with and without an ankle weight equal to 5% of total body weight, while ground reaction forces were collected via a force platform. The highest frequency required to reconstruct the 99% of the signal's power in each direction was calculated from the ground reaction forces.

Results: The added ankle weight significantly decreased the frequency content in the mediolateral direction for the young. The frequency content significantly increased in the other two directions (vertical and anterior-posterior) for both groups. The elderly had a significantly higher frequency content compared with the young in the anterior-posterior direction.

Conclusions: Aging differences were detected using the frequency domain analysis. The added ankle weight significantly altered the frequency content characteristics of the ground reaction forces.

Relevance: A frequency domain analysis of the ground reaction forces can be a useful tool to identify changes in gait due to age-related impairments.

Keywords: walking, ground reaction forces, ageing, frequency domain analysis

1. Introduction

The literature {Bohannon, Andrews, et al. 1996 30 /id}{Feltner, MacRae, et al. 1994 102 /id}{Ferrandez, Pailhous, et al. 1990 103 /id}{Winter, Patla, et al. 1990 302 /id} reports changes in gait parameters of elderly adults including decreases in step frequency, step length, and walking speed. However, limited research exists regarding kinetic differences and, specifically, ground reaction forces (GRF) {Kerrigan, Todd, et al. 1998 174 /id}. Standard GRF evaluations performed with young volunteers typically use time domain parameters {Chao, Laughman, et al. 1983 55 /id}{Hamill & McNiven 1990 138 /id}. However, these parameters may lead to erroneous conclusions in cases when two different trials of the same person are examined before and after treatment; they might have nearly the same time domain parameters and having no apparent treatment effect (Giakas et al., 1996).

Frequency domain analysis has been previously used to assess normal {Antonsson & Mann 1985 14 /id}{Alexander & Jayes 1980 5 /id}{Chao, Laughman, et al. 1983 55 /id}{Crowe, Schiereck, et al. 1993 71 /id}{Giakas & Baltzopoulos 1997 118 /id} and pathological {Giakas, Baltzopoulos, et al. 1996 114 /id}{Jacobs, Skorecki, et al. 1972 160 /id}{Schneider & Chao 1983 245 /id}{White, Agouris, et al. 1999 291 /id} gait. Such an analysis has the potential to assist in identifying changes in gait due to age-related impairments or in evaluating the treatment of gait disorders. .

The study of variability in gait parameters can yield important insights. Recently it was shown that variability in cadence is an important predictor of fall risk in elderly population, {Hausdorff, Rios, et al. 2001 327 /id}{Hausdorff, Nelson, et al. 2001 328 /id}. Variability and reliability of GRF patterns during walking have previously been examined in various populations and conditions {DeVita & Bates 1988 86 /id}{Giakas & Baltzopoulos 1997 118 /id}{Hamill & McNiven 1990 138 /id}, but not for the elderly .

The purpose of this study was to examine the frequency domain characteristics and variability of the GRF of young and older individuals during walking. We are particularly interested in how GRF frequency characteristics changed while walking with a unilaterally increased lower extremity loading. We hypothesized that the elderly will exhibit higher frequency content in comparison with the young group. In addition, we attempted to augment the differences between the two groups by unilaterally adding an ankle weight. We hypothesised that the elderly will be more affected by the added ankle weight as exhibited by changes in the frequency content of all GRF components.

2. Methods

Written consent was given by ten healthy young [age 24.6 (SD, 3.2) years; mass 61 (SD, 10) kg] and ten healthy elderly [age 73.7 (SD, 4.9) years; mass 62.6 (SD, 5.8) kg] females with no clinical history of falling or any other musculoskeletal or neurological problems. A Kistler (Type 9281-B11, Amherst, NY) force platform system sampling at 960 Hz was used to collect GRF during walking. The walking speed was recorded using a photo-electronic timing system.

The subjects were asked to walk at a comfortable speed. The walking distance for each trial was approximately 15 meters. Each subject performed at least 10 walking trials for familiarization with the experimental setting. Subjects wore their regular sports shoes to assure normal and comfortable performance. Regular resting breaks were given so the subjects would not experience undue fatigue. The comfortable walking speed was recorded in all trials. When this speed was constant for three subsequent trials the subjects were considered ready for recording. Every subject was required to walk at this speed (± 5%) with and without an added ankle weight. This ensured compatibility between the two conditions, as speed is highly correlated to ground reaction forces {Andriacchi, Ogle, et al. 1977 11 /id}. The ankle weight (Keiser; Model #60-0863) was attached to the right ankle using an adjustable strap and it was equal to 5% of the subject's body weight. The selection of this specific percentage was based upon pilot work and the literature {Graves, Martin, et al. 1988 129 /id}{Miller & Stamford 1987 205 /id}{Skinner & Barrack 1990 254 /id}. Each condition consisted of 10 trials, for a total of 20 trials per subject.

Overall, there were 400 trials (2 groups X 2 conditions X 10 subjects X 10 trials). In each trial the mediolateral (M-L) the anterior-posterior (A-P) and the vertical (V) components of the GRF were recorded. Each signal was transformed in frequency domain and the power spectral density was calculated using MATLAB. We used a similar criterion developed previously {Giakas, Baltzopoulos, et al. 1996 114 /id}{Giakas & Baltzopoulos 1997 118 /id}{White, Agouris, et al. 1999 291 /id}, but instead of using the amplitude of the harmonics, we used the cumulative power to reconstruct a certain amount of the signal. We tested five levels of the power spectrum; 90% - 95% - 99% - 99.5% - 99.9%. The bottom two (90% and 95%) were not sensitive enough because they needed just 3-5 harmonics, so they created zero standard deviations between trials, while the top two (99.5% and 99.9%) were too sensitive. The 99% level of the signal power was sensitive enough and more representative of each signal characteristics and was used as the criterion. Subsequently, mean and the standard deviation values were calculated for the frequency criterion across trials for each condition of each subject for the three force components. Group means were also calculated for each condition. The intra- and inter- subject variability was also determined by calculating the coefficient of variation from the 10 trials of one subject and the total number of subjects, respectively .

Two-way ANOVAs (age by weight) with repeated measures on the weight factor were performed on the subject means, for each force component for the frequency criterion. A Tukey multiple comparison post-hoc analysis was performed to identify the location of the significant differences for the tests resulting in a significant F-ratio ($p<0.05$).

3. Results and Discussion

The mean mediolateral frequency (M-L) had the highest frequency content (gross mean 22 Hz), followed by the anterior-posterior (A-P) (15 Hz) and by the vertical (V) (13 Hz) components (Figure 1). This is in agreement with previous studies examining young adults {Giakas & Baltzopoulos 1997 118 /id} and adolescents with scoliosis {Giakas, Baltzopoulos, et al. 1996 114 /id}.

The ankle weight significantly ($p<0.01$) increased the frequency content in the A-P and V directions for both groups. In the A-P, the frequency content significantly ($p<0.01$) increased by 28% and 29% for the elderly and for the young groups, respectively. Similarly for the V direction, the frequency content significantly ($p<0.01$) increased by 15% and 12%, respectively. However, the added ankle weight decreased the frequency content in the M-L direction in the elderly group by 7% and in the young group by 29%. This unequal decrease between the two groups resulted also in a significant interaction ($p<0.05$). The post-hoc analysis indicated that this decrease was significant only for the young group ($p<0.01$). This result is in contrast to our hypothesis that the added ankle weight will increase the frequency content in all GRF components. It is possible that the young subjects detected the asymmetrical loading and its effect on sideways stability, thus decreasing the frequency content to complete the activity in a successful and safe manner. Regarding the age main effect, the A-P direction revealed significantly ($p<0.01$) less frequency content values for the young group by 2.5 Hz. This decrease in the A-P frequency content may be due to the differences in the walking speed; the young subjects walked 0.19 m/s faster than the elderly (Young: 1.43 m/sec; Elderly: 1.24 m/sec). Walking is a sagittal plane movement and speed differences will be reflected mostly in the A-P. No differences were identified for the other two GRF components.

All these results have to be viewed in light of the intra- and inter-subject variability (Figure 2). The added ankle weight did not alter the intra-subject variability in the M-L in both groups, but had opposite effects on the inter-subject variability. The young group showed a decrease from 37% to 13%, but for the elderly variability increased from 17% to 29%. In the A-P and V components, the intra- and inter-subject variability for the young group was doubled after the ankle weight was introduced but remained approximately 13%. The elderly group exhibited high variability in the A-P direction (approximately 15%), which slightly increased with the added ankle weight.

A limitation of the present study is that the elderly subjects were not screened by a geriatrician for occult clinical conditions. Subjects themselves may or may not recognize that they have had a mild stroke, a mild peripheral neuropathy, or other central or peripheral conditions that can affect gait. Thus, they may report themselves as healthy even with an impairment. The results of the present study should be viewed with this limitation in mind.

In summary, this study demonstrated that the added ankle weight significantly altered the frequency content characteristics of ground reaction forces. The frequency content increased in the mediolateral direction, but decreased in the other two components. In addition, differences between the young and elderly were found in both the anterior-posterior and the mediolateral directions.

Figures

Figure 1. Mean GRF frequency content by group and condition. Bars indicate standard deviations. Gianni, why the bars are standard deviations. I know that the reviewer said so but the way you had them before it was the correct way. '#' indicates a significant ($p<0.05$) group effect, '*' symbol indicates a significant limb weight effect and '&' indicates a significant interaction. Giavvi, you need to place an "&" over the young M-L. An interaction is significant for both groups. We indicated what the post-hoc analysis showed in the document. Also, place an "#" over the young A-P to indicate that the main effect for age was significant. A main effect can not be significant just for one age group.

Figure 2. Inter- and intrasubject GRF coefficient of variation by group, condition and GRF component.

Figure 1

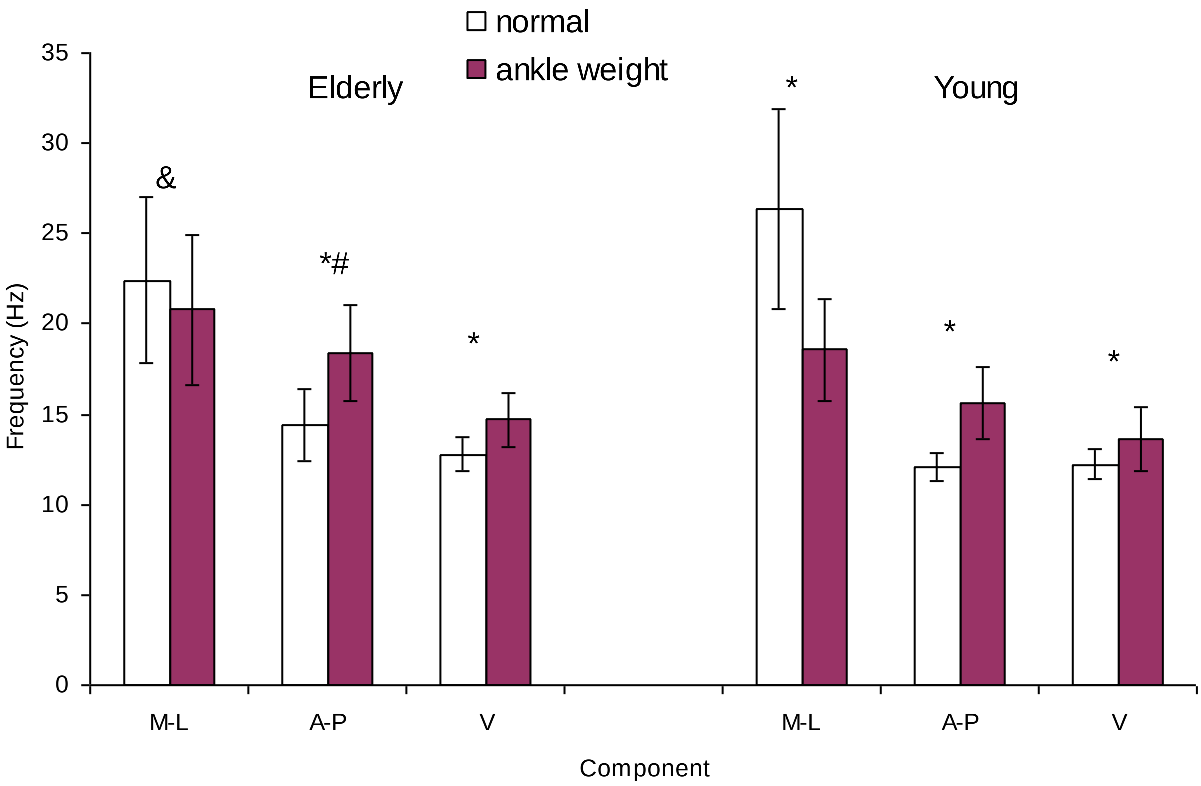
normal
ankle weight
Elderly
Young
Frequency (Hz)
35
30
25
20
15
10
5
0
&
*#
*
*
*
*
M-L
A-P
V
M-L
A-P
V
Component

Figure 2

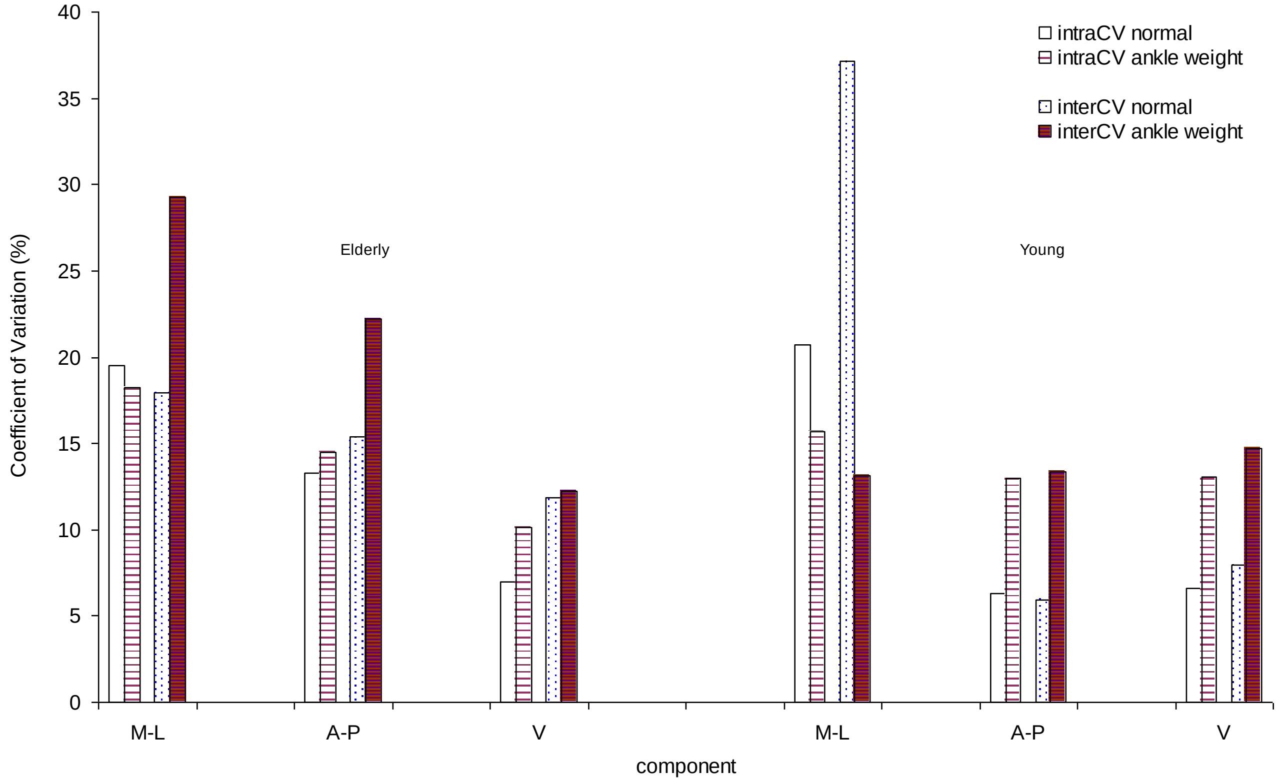
40
35
30
25
20
15
10
5
0
Coefficient of Variation (%)
intraCV normal
intraCV ankle weight
interCV normal
interCV ankle weight
Elderly
Young
M-L
A-P
V
M-L
A-P
V
component

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Table 1
Mean (SD) GRF frequency content values (Hz) of each GRF component for both groups

	Young ($n = 10$)	Elderly ($n = 10$)	P-value
M-L	22.40 (4.57)	26.35 (5.54)	0.100
A–P	14.38 (2.02)	12.06 (0.80)	0.002*
Vertical (V)	12.75 (0.94)	12.21 (0.84)	0.170

The P-values for the three t-tests between groups are also listed.
* indicates a significant difference at the 0.05α level.

Table 2
Inter- and intra-subject coefficient of variation of the frequency content of each GRF component for both groups

GRF component	Young ($n = 10$)		Elderly ($n = 10$)	
	IntraCV	InterCV	IntraCV	InterCV
M-L	20.69	37.12	19.50	17.91
A–P	6.32	5.95	13.32	15.36
Vertical (V)	6.59	7.99	6.95	11.89