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Original Research

Frequency Content of Ground Reaction Forces during Walking: A Comparison in the Elderly Fallers and Non-Fallers

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ABSTRACT

With the increase in the elderly population, the rate of their falls has also increased significantly and causes serious damage to the health of the elderly and society. Falling causes kinematic and kinetic changes in walking of the elderly. Ground reaction force (GRF) is often measured in gait and fall studies and analyzes and is considered as a criterion for walking evaluation. However, to date, no research has been done on the frequency content of GRF in elderly falls, which appears to be able to identify patterns leading to falls and injuries in the elderly. 22 active elderly women aged 65 to 75 years volunteered for this research. They were grouped into two groups of 11 people with and without a history of falling. The subjects walked along the designated path in the gate lab, the walking data was recorded with a force plate. The frequency content of GRF was extracted by fast Fourier transform (FFT) and MATLAB 2016 software. Results: This study compared the frequency content of GRF during walking in elderly people with and without a history of falls. The results shown that F99.5% in the anterior-posterior direction and Fmed in the anterior-posterior direction in the fallen group were significantly higher than the non-fallen group. And it did not show any significant change in other trajectories and other variables. It was found that the fallers showed different frequency content. Performing GRF frequency content assessment has the potential to identify fall-related injuries in affected individuals.

Keywords: Elderly, Frequency content, Gait, Ground reaction force, Walking

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INTRODUCTION

Advancements in the realm of healthcare and technology have yielded a surge in projected lifespan and a consequent rise in the demographic of senior citizens. According to forecasts, the geriatric demographic is anticipated to augment from 550 million to 973 million within the period spanning from 2000 to 2030 [1]. The rising demographic of older adults has been accompanied by a marked increase in the incidence of falls which have been shown to have deleterious effects on the health status of this age group as well as their immediate families and, more broadly, the wider society [2]. Falls represent a prominent contributing factor towards injury and mortality in the elderly population, underscored by its significance as a pivotal public healthcare concern. According to scholarly sources, falls are the prevailing factor leading to unintentional injuries among the aging demographic [3]. Advancing age represents the most substantial risk factor for the development of functional limitations. Alongside the natural process of aging, alterations associated with the configuration, dynamics, and operation of the foot take place [4-6].

It is widely recognized within academic literature that falls have a negative impact on an individual's quality of life, particularly their sense of independence. This is attributed to an increase in anxiety and fear surrounding the possibility of falling, which subsequently reduces confidence in performing daily tasks. Consequently, this will diminish their ability to execute motor tasks and engage in physical exertion. Conversely, the diminishment of motor performance and reduced physical activity prove to be significant hazards for falls amongst elderly individuals [10-13, 15, 16, and 18]. The promotion of mobility is recognized as a substantial constituent of promoting healthy aging among the elderly population, as indicated by various studies [14, 19]. Several scholarly investigations have demonstrated that decreases in fundamental spatial-temporal gait measures, that is to say, the characteristics pertaining to the space and time dimensions of walking, have been observed. The present investigation has shown statistical significance between locomotive variables including velocity and step length and physiological factors that have been identified as risk factors for falls. These factors include lowered lower limb strength, slow reaction time, escalated postural sway, compromised peripheral neuropathy, and diminished visual acuity, as reported in previous research [20].

The fundamental parameters of human locomotion, commonly referred to as gait, have the potential to serve as valuable comprehensive indicators of ambulatory function. However, it is important to note that these parameters do not offer insights into the postural steadiness of the body [20]. The act of walking represents a fundamental ability that constitutes a critical component of the daily physical activity of the human species [21]. Falls are a considerable concern in the geriatric population, with walking being the predominant activity leading to such incidents. Evaluating walking performance represents an effective approach for a comprehensive assessment of fall risk [22, 24].

The findings of the study revealed a noteworthy increase in peak torque for various movements namely, hip flexion, hip adduction, knee extension, knee varum, ankle dorsiflexion, and ankle eversion within the falls group. The study results indicate a significant reduction in ankle plantarflexion torque within the falls group [25]. The individuals who experienced falls exhibited decreased walking speed and stride length coupled with increased variability in step duration compared with their non-fellows counterparts. The duration of maximal weight acceptance and mid-stance in fallers was notably greater when compared to non-fallers. The findings of this study indicate that incorporating spatio-temporal variables and Ground reaction force (GRF) variables can prove beneficial in differentiating individuals at risk of falling (prospective fallers) from those who are not (non-fallers), particularly among the elderly population [26].

The biomechanical factor of GRF has received inadequate attention in research studies pertaining to the gait and fall-related issues in elderly individuals. The measurement and analysis of GRF frequently constitute a pivotal element in studies which explore locomotion, and serve as a prominent criterion in the evaluation of walking gait [25]. The investigation of biomechanical parameters in the context of walking and falling among the elderly remains an area that warrants further inquiry. Specifically, the frequency content of GRFs is a significant parameter that has yet to be fully explored. Analysis of this parameter has the potential to serve as a valuable non-invasive tool in the evaluation of walking and falling among the elderly population. Thus far, there have been limited endeavors to scrutinize the frequency spectrum of ground reaction forces among the aged population. The spectral characteristics of GRF have the potential to identify and elucidate the underlying causes of falls [26]. Jafarnezhadgero et al., (2020) conducted a comparison between a group of healthy individuals and a group suffering from back pain. Their findings suggest that the decreased values of various frequency components observed in the latter group may be attributed to the guarded gait mechanism that is utilized by individuals with back pain [27]. Additionally, patients with moderate diabetic neuropathy may experience abnormalities in the frequency contentment of lower limb muscles during walking, which can be attributed to damage to peripheral nerves caused by the neuropathy. The reduction in functional capability of the lower limb muscles may result in inadequate regulation of ground reaction forces, thereby escalating the probability of injury and falls among patients [28]. The exploration of frequency domain analysis holds the promise of discerning alterations in the manner of walking that may be concealed within the time domain [29, 30].

Efforts have been made to examine falling through biomechanical investigations, which involve the characterization of the modulation of balance control during different activities such as standing, walking, postural transitions, and responding to unexpected perturbations and endeavors to augment the existing body of knowledge on fall risk by means of complementary studies in the fields of epidemiology and physiology. Moreover, biomechanical research can facilitate the design of effective techniques for preventing injuries through the training of safer falling methods. Additionally, the assessment of the impact of such techniques can be evaluated through further biomechanical analysis [20].

The concept of gait has been linked to a significant risk factor for falls among the elderly population. It is imperative to discern variances in quantitative parameters of gait patterns between individuals with incidents of falling and those without any history of falls. The primary objective of the present study was to examine the frequency characteristics of GRFs during gait in elderly individuals who have experienced falls and those who have not.

MATERIAL AND METHODS

Participants

As per the analysis conducted by software G*Power3.1 (3.1.5 Freeware. University of Dusseldorf, Dusseldorf, Germany), it was shown that for an effect size of 0.8, statistical power is 0.9 and the significance level is 0.05, In the independent t-test, The minimum number of required samples size is 19 people.

The sample size was calculated using G*Power version 3.1.5 software, with an effect size of 0.8, a significance level of 0.05 and a power of 0.80. 22 active elderly women aged 65 to 75 years volunteered for this research with at hand method. They were divided into two groups with and without a history of falling, and there were 11 people in each group. The demographic information of the participants is shown in Table 1.

The study assessed the fall status of 22 participants by asking them to complete a self-report questionnaire. The questionnaire inquired about their fall history in the past 12 months, the number of falls they experienced, and the cause of each fall. A fall was defined as any incident where the participant unintentionally made contact with the ground or floor. Participants were then categorized into two groups: fall group (n=11) if they had fallen at least once in the previous year, and non-fall group (n=11) if they did not have any falls in the past year.

Table 1. Demographic information of the participants

Variable	Weight (kg)	Height (Cm)
Fallers (n=11)	65.73 ± 12.47	160 ± 7.51
Non-Fallers (n=11)	62.45 ± 10.80	159 ± 11.58
N=22		

Instruments and Examinations

Research procedure

This study was conducted in a comparative causal design with the aim of comparing GRF frequency content in two groups of fallers and non-fallers among the elderly women, retrospectively. The present study Ethics code has been issued in research from the Sport sciences Research Institute of Iran to the number SSRI.REC-2212-1977.

Fall, Fallers and Non-fallers definition

A fall is described as any occurrence where the participant unintentionally makes contact with the ground or floor. The participants consciously filled out and approved questionnaire forms regarding their health, daily physical activity levels, and consent [31].

Definition of dependent variables

The study computed the frequency that encompassed 99.5% of the signal (F99.5%) for the vertical, anterior-posterior, and medial-lateral GRF. The median frequency (Fmed) was determined at the point where half of the signal power was above and half was below [30, 33]. The frequency bandwidth (Fband) was calculated as the difference between the maximum and minimum frequency when the power was greater than half of the maximum power [30, 33]. Lastly, the 99.5% frequency F99.5% was identified as the frequency at which 99.5% of the power spectrum was contained [30, 33].

Protocol

The participants were given recommendations on suitable clothes and same sports shoes to wear, and were instructed to warm up their bodies before the test. The Gait test data was recorded using a Force plate, while the study involved participants walking on a walkway at their self-selected speed and in their preferred procedure. Specifically, the dominant leg was placed on the Force plate on the third step, followed by the non-predominant leg on the other Force plate, and then continued walking until the end of the path [32].

Each participant's three successful attempts were recorded and averaged for calculations. Looking at the force plate, walking abnormally (such as frozen walking or like a robot), not placing the feet completely on the force meter plate or in case of any malfunction in recording the test data, the test had repeated again (Figure 1a,1b).

Figure 1a. Gait lab before the test

Figure 1b. Gait lab during the test

Statistical Analysis

Shapiro Wilk test was used as normality test among the variables. The alpha-level for significance was set at 0.05. F99/5% in two groups in the anterior-posterior direction (in fallers group: p="0/478">0.05 and in non-fallers group p="0/380">0/05) and the medial-lateral direction (in fallers group: p="0/230">0/05 and in non-fallers group p="0/400">0/05) had a normal distribution at a significance level of (p-value>0/05). And none of the other variables had normal distribution in any of the directions. Independent t- test (parametric method) and U-Mann Whitney test (non-parametric method) were used for evaluation The difference in frequency content between the two groups elderlies with and without a history of falling at a significance level of (p-value<0/05) and Confidence Interval 95%. All statistical analyses were performed using SPSS 22 software (SPSS Inc., Chicago, IL, USA). In each GRF frequency feature independent t-test (for F99/5% in the anterior-posterior and medial-lateral direction) and U-Mann Whitney test (for vertical direction of F99.5%, and Fmed and Fband in the all 3 Trajectories).

Data analysis

After collecting the data, the 4th order Butterworth method was used to remove possible noises [32].To find the cutoff point, the residual method was used and the data was filtered with a cutoff point of 42. After filtering the GRF data, harmonic analysis was converted from time function to frequency function.

The dependent variables of Fmed, Fband and F99/5%, for the vertical, anterior-posterior and medial-lateral GRF, were calculated.

Equation 1. $F(t) = \sum_{n=1}^{\infty} A_n \, sin(n\omega_0 \mathrm{t} + \theta_n)$

Equation 2.

Equation 3. $\int_0^{f\ med} p(f)df = \int_{fmed}^{fmax} p(f)df$

Equation 4. $\mathrm{f}_{band} = f_{max} - f_{min}\ (when\ p > 1/2 \times p_{max})$

This involved converting the anterior-posterior, medial-lateral, and vertical GRF of each trial to the frequency domain. We achieved this by using the fast Fourier transformation (FFT) feature available in MATLAB software version 2016. We used FFT, to convert complex signals from time function to frequency function as a sum of sinusoidal functions with different frequencies. By

decomposing the frequency by fast Fourier transform, the amount of movement (amplitude) at each frequency is calculated. In the motion signal, the frequency function is usually based on the basic harmonic and its spectrum is shown discretely.
Simple example of a signal is shown in Figure 2 which is the sum of three sinusoidal signals with different frequencies. By decomposing the frequency by fast Fourier transform, the amount of movement (amplitude) at each frequency is calculated. In the motion signal, the frequency function is usually based on the basic harmonic and its spectrum is shown discretely [32].

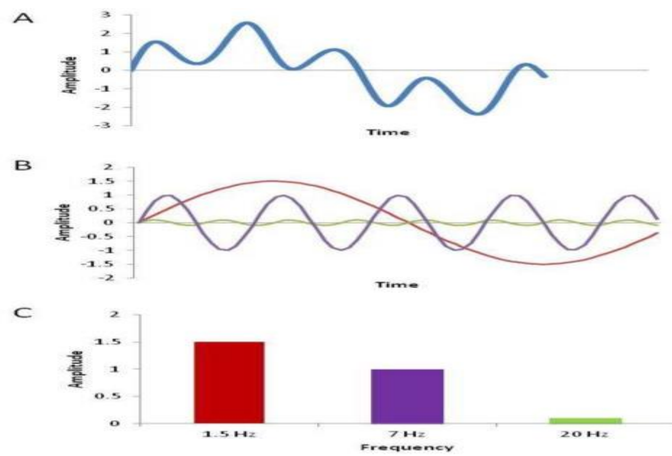

Figure 2. Fast Fourier transform of a sinusoidal signal, adapted from McGrath et al, 2012. (Graphs A and B display signals in the time domain, while graph C illustrates the same signals in the frequency domain).

RESULTS

The aim of this study was to compare the frequency content of GRF due to falls in the elderly. Therefore, we compared the three desired variables, including frequency F99.5%, Fmed and Fband in two groups were applied at any point to check whether the frequency content of the fallen and non-fallen, GRF showed a significant difference ($p<0.05$) and Confidence Interval (CI=95%) which are shown in Table 2.
Our results showed that:

Table 2. Comparison of Frequency content of the GRF in two research groups

Direction	Variable	Fallers	Non fallers	P-value
Anterior- posterior	**F99/5%**	11.90 ± 2.94	10.18 ± 2.14	0.021 *
Medio- lateral	**F99/5%**	12.91 ± 3.84	11.18 ± 2.19	0.420
Vertical	**F99/5%**	7.72 ± 2.37	8.18 ± 2.75	0.784
Anterior- posterior	$\mathbf{F_{med}}$	2.01 ± 0.72	1.68 ± 0.46	0.043*
Medio- lateral	$\mathbf{F_{med}}$	2.05 ± 0.82	1.77 ± 0.34	0.699
Vertical	$\mathbf{F_{med}}$	2.73 ± 0.62	1.05 ± 0.62	0.499
Anterior- posterior	$\mathbf{F_{band}}$	1.15 ± 0.22	1.94 ± 0.12	0.478
Medio- lateral	$\mathbf{F_{band}}$	1.45 ± 0.52	1.55 ± 0.52	0.748
Vertical	$\mathbf{F_{band}}$	1.87 ± 0.40	1.99 ± 0.61	0.844

Note: Significant difference ($p<0.05$). F99/5%: The contained 99.5 percent of the signal, F_{med}: The median frequency, F_{band}: Frequency bandwidth.

The frequency F99/5 percent of the ground reaction forces (F99/5 %)

The frequency F99/5 percent of the ground reaction forces (F99/5 %), which were investigated separately in three directions, is shown in Table No.2. To compare the two groups in this variable in the anterior-posterior direction and the medial-lateral direction from the independent t-test and in the vertical direction, U Mann-Whitney's test was used with a significant level ($p < 0/05$) and (CI=95%).

The result of the statistical test analysis for comparing two groups in this variable and direction, shows that the two groups have a significant difference in this variable ($p=0.021<0/05$). The value of this variable in the fallers elderly was significantly higher than non-fallers elderly (Table 2).

The Mid frequency of the ground reaction forces (F_{med})

The Mid frequency of the ground reaction forces (F_{med}), which were investigated separately in three directions, is shown in Table 2. To compare the two groups in this variable in the all three directions from U Mann-Whitney's test was used and with a significant level ($p < 0.05$).

The results of the statistical test analysis to compare the two research groups in the anterior-posterior direction show that the two groups have a significant difference ($p=0.043<0.05$). The value of this variable in the fallers elderly was significantly higher than non-fallers elderly (Table 2).

The frequency bandwidth of the ground reaction forces (Fband)

The frequency bandwidth of the ground reaction forces, specifically in the three directions of investigation, is shown in Table 2. To compare two groups in this experiment in all three directions, the U-Man-Whitney test was used at a significance level of 0.05 and a confidence interval of 95%. The results of the analysis and analysis of the statistical test to compare the two research groups in all three directions anterior-posterior, medial-lateral and vertical show that the two groups did not show any meaningful difference.

DISCUSSION

Gait is a critical risk factor for falls in the elderly population, and it is crucial to identify quantitative gait variable differences between fallers and non-fallers. This study aimed to investigate the frequency content of GRF in elderly fallers and non-fallers during walking. Two groups of active elderly women with and without a history of falling were tested in a Gait laboratory to compare the frequency content of GRF during walking. The study examined the variables of F99/5%, F_{med}, and F_{band} in GRF frequency content. Results showed that fallers exhibited different frequency content, indicating that assessing GRF frequency content may identify fall-related injuries in affected individuals. This study's findings suggest that performing GRF frequency content assessment has potential in identifying fall-related injuries in the elderly population.

Our research revealed that in the fallers group, F99/5% in the anterior-posterior direction was significantly higher (11.90±2.94) compared to the non-fallers group (10.18±2.14), which is consistent with the findings of Anoushiravani et al., (2022) and Eslami et al., (2015). Additionally, Fmed in the anterior-posterior direction in the fallers group was significantly higher (2.01±0.72) than the non-fallers group (1.68±0.46), This finding aligns with the outcomes reported by Eslami et al., (2015) and Abdollahpour et al., (2020) These findings suggest that an increase in frequency content leads to instability and slippage in the movement pattern, potentially contributing to falls in the elderly population [33,34], This instability in the walking pattern is probably one of the contributing factors to falls in the elderly fallers.

And According to Sterigo et al., (2002) lower frequency content indicates slower oscillations during movement [36]. Therefore, less fluctuations can represent a better counter-posture in the elderly without a history of falling. F99/5% and f_{med} did not show a significant difference in the medial, lateral and vertical directions in the two groups, and there was no significant difference in the f_{band} variable in any of the three directions. The high frequency content in fallers elderly is probably a sign of some kind of change in the function of the organs, which reduces the function and efficiency of the neuromuscular system and efficiency of the neuromuscular system and confirms the results of Anoshirvani et al. that the frequency spectrum of GRF has clinical value [37].

In the medial-lateral direction, none of the three variables showed a significant difference in GRF frequency content. According to Winter (2009) in the analysis of walking and running, this GRF component shows the balance and stability of the person in the frontal plane [38]. Therefore, it seems that elderly people with a history of falling probably use compensatory processes to maintain balance and stability of walking. Researchers have also stated that the frequency bandwidth is related to all the components of the neuromuscular system, bones, muscles and connective tissue that cooperate with each other to produce movement for example, the reduction of the bandwidth of motion frequencies indicates the limitation of the oscillation phenomena in one or more of these structures [30]. However, the results of the present study did not show a significant difference in the frequency bandwidth of ground reaction forces between two groups of elderly people with and without a history of falling, which showed that it is consistent with the result of Jafarnezhadgero et al., [28]. Differences in GRF during walking were observed between fallers, non-fallers, and velocity-matched controls. Notably, these differences were present in both fallers and non-fallers, suggesting that analyzing GRF frequency content may be a useful tool for quantifying long-term changes associated with falling in elderly individuals. Regular evaluation of GRF during walking in the elderly may aid in understanding changes in gait and predicting fall risk, ultimately preventing harmful accidents. This information can also inform the development of exercise programs tailored to ameliorate walking and balance in elderly individuals. Further research is necessary to fully explore this topic.

Additionally, this analysis detected higher oscillatory movement patterns in elderly fallers during walking compared to non-faller elderly. Therefore, these measures can potentially evaluate the long-term and short-term effects of surgical interventions, exercise, and drug treatments for elderly people who have fallen. Our conclusion is that this type of biomechanical analysis holds great potential for clinical applications. It can provide new insights into the gait impairments that are associated with falling. The implementation of such an analysis is feasible in a clinical setting since subjects would only need to walk over a force platform to obtain the data. There would be no need to attach any devices to the patients. Moreover, as combined training has been shown to be effective in improving motor control and balance in elderly individuals, and decreasing the risk of falls [39], it may be possible to use the results of such evaluations in designing fall prevention exercises for the elderly. Future research should investigate the relationship between the higher frequency phenomenon noted in fallers and non-fallers elderly, while simultaneously measuring lower extremity muscle electrical activity. Additionally, the relationship between higher movement frequencies in the pain versus pain-free condition and falls history or falls risk should also be investigated.

CONCLUSION

This study investigated the frequency content of GRF during walking in elderly individuals with and without a history of falls. The results showed that fallers had different frequency content, and assessing GRF frequency content could potentially identify fall-related injuries. Understanding the differences in walking patterns caused by falls in the elderly population can provide solutions for fall prevention and recovery. These findings can help improve fall risk predictive models for elderly survivors of falls and design effective fall risk prevention paradigms that can be adjusted grounded on the type of fall risk. Implementing such fall risk evaluation and avoidance paradigms has the potential to decrease fall-related injuries in the elderly and decrease associated hospital costs.

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Institutional Review Board Statement: The current research protocol was approved by the ethics committee of the Research Institute of Physical Education and Sports Sciences with the number IR. SSRI.REC-2212-1977.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest

The authors declare no conflict of interest.

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محتوای فرکانس نیروهای عکس العمل زمین در سالمندان (مقایسه ای میان سالمندان با و بدون سابقه افتادن)

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چکیده:

با افزایش جمعیت سالمندان، میزان افتادن آنها نیز افزایش چشمگیری داشته و آسیب جدی به سلامت سالمندان و جامعه وارد می کند. زمین خوردن باعث تغییرات حرکتی و جنبشی در راه رفتن سالمندان می شود. نیروی واکنش زمین (GRF) اغلب در مطالعات راه رفتن و افتادن، اندازه گیری می شود و به عنوان معیاری برای ارزیابی راه رفتن در نظر گرفته می شود. با این حال، تا به امروز، هیچ تحقیقی در مورد محتوای فرکانس GRF در افتادن سالمندان انجام نشده است، که به نظر می رسد قادر به شناسایی الگوهای منجر به افتادن و آسیب در سالمندان باشد.۲۲ زن سالمند فعال ۶۵ تا ۷۵ ساله برای این تحقیق داوطلب شدند. آنها به دو گروه ۱۱ نفره با و بدون سابقه افتادن دسته بندی شدند. آزمودنی ها در امتداد مسیر تعیین شده در آزمایشگاه گیت راه رفتند، داده های راه رفتن با صفحه نیروسنج ثبت شد. محتوای فرکانسی GRF توسط مبدل سریع فوریه (FFT) و نرم افزار متلب نسخه ۲۰۱۶ استخراج شد. این مطالعه محتوای فرکانسی GRF را در حین راه رفتن در سالمندان با و بدون سابقه زمین خوردن مقایسه کرد و نشان داد که F99.5% در جهت قدامی خلفی و Fmed در جهت قدامی خلفی در گروه زمین خورده به طور معنی داری بیشتر بود. و در سایر متغیرها و سایر جهات تفاوت معنا داری را نشان نداد.مشخص شد که سقوط کنندگان محتوای فرکانس متفاوتی را در بعضی متغیر های طیف فرکانس GRF نشان می دهند. انجام ارزیابی محتوای فرکانس GRF پتانسیل شناسایی آسیب های مربوط به افتادن در افراد مبتلا را دارد.

واژه های کلیدی: افتادن، راه رفتن، سالمند، محتوای فرکانس، نیروهای عکس العمل زمین