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Higher Levels of Physical Fitness Are Associated with Lower Peak Plantar Pressures in Older Women

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Received: 8 April 2020; Accepted: 16 May 2020; Published: 18 May 2020

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Abstract: Little is known about how physical fitness is associated with peak plantar pressures in older adults. Therefore, the main purpose of the study was to explore whether higher physical fitness levels were associated with lower peak plantar pressures in a sample of community-dwelling older adults. In this cross-sectional study, we recruited 120 older women aged ≥60 years. To assess the level of peak plantar pressure, we used a Zebris plantar pressure platform. To estimate the level of physical fitness, a senior fitness test battery was used. To calculate the associations between the level of physical fitness and peak plantar pressures beneath the different foot regions (forefoot, midfoot and hindfoot), we used generalized estimating equations with a linear regression model. In unadjusted models, higher physical fitness levels were associated with lower peak plantar pressures. When we adjusted for chronological age, the risk of falls and the presence of foot pain, higher physical fitness levels remained associated with lower peak plantar pressures. Our study shows that higher levels of physical fitness are associated with lower peak plantar pressures, even after adjusting for several potential covariates.

Keywords: older adults; exercise; correlation; foot; biomechanics

1. Introduction

The percentage of older adults aged ≥65 years has risen dramatically in the last 50 years [1]. It is estimated that the number of older adults will significantly increase in the next 30 years [1]. During the aging process, older adults suffer from a higher prevalence of chronic diseases [2], steadily losing the ability to perform activities in everyday living. Additionally, the number of disabilities doubles and physical limitations quadruples after the age of 60 [3].

The most important factor of aging is being independent and maintaining a high life quality [4]. However, age-related loss of muscle mass and greater accumulation of fat mass often lead to a significant decline in physical performance [5]. Previous evidence has shown that poor physical performance is associated with several health-related consequences, including higher risk of falls [6], higher incidence of chronic diseases [7] and mortality [8]. Physical performance is often associated with physical fitness [9], the capacity needed to undertake daily activities [9]. The level of physical fitness tends to reduce during aging, in terms of strength, endurance, flexibility and agility [10,11]. Such a decrease is often accompanied by a skeletal muscle and joint motion loss and an increment of fat mass [9].

It has been well-documented that elderly individuals have altered foot characteristics, including higher plantar pressures during walking [12]. Such a condition may cause lower extremity pain and discomfort [13], tending to discourage these individuals from achieving higher physical fitness levels.

Measuring peak plantar pressure beneath different foot regions is of significant clinical importance, because it is postulated that older adults with abnormal foot posture and balance performance may be of higher risk of generating higher peak plantar pressure loads [14]. One previous study has shown that total physical activity and time spent in moderate-to-vigorous physical activity are significantly and inversely correlated with peak plantar pressures across the heel region of the foot [15]. Another study using similar methodology has shown similar results, i.e., moderate-intensity, vigorous-intensity and moderate- to vigorous-intensity physical activity are significantly and inversely correlated with peak plantar pressures across the middle and lateral forefoot region and the lateral midfoot region of the foot [16]. However, both studies were conducted among children and used objectively measured physical activity as an outcome variable. Evidence shows that older adults suffer from an increased risk of osteoarthritis, myopathies and pain incidence, which often affect walking ability through a reduced muscle strength and endurance [17]. These individuals with lower levels of muscle mass and impaired muscle strength are unable to perform everyday activities and have deviated walking abilities, leading to increased peak plantar pressures [18]. Although physical activity and physical fitness are often closely related, they have been moderately correlated with at times great variability [19]. Thus, the correlations between physical activity and physical fitness and peak plantar pressures may not be the same.

We found no study into available literature that has systematically explored the associations between the different components of physical fitness and peak plantar pressures under the different foot regions. Therefore, the main purpose of the study was to explore whether higher physical fitness levels were associated with lower peak plantar pressures in a sample of community-dwelling older adults. We hypothesized that higher physical fitness levels would be associated with lower peak plantar pressure beneath the different foot regions.

2. Materials and Methods

2.1. Participants

This is a cross-sectional study in which older adults aged ≥60 years from five neighborhoods in the city of Zagreb were recruited. The study protocol and sample size collection are described elsewhere [20]. First, we introduced the study methodology via posters. Of an estimated population of 1500 adults aged ≥60 years living in five neighborhoods, the estimated sample size for the confidence level of 95% and confidence interval of 10% was 110. In order to correct for possible missing data, we recruited 210 participants, of whom 73 did not provide full data and 17 could no longer be in the study due to personal issues. Finally, we based our study on 120 older women (100%). The inclusion criteria were: (1) being ≥60 years old; (2) living independently in the community; (3) passing the short portable mental status questionnaire; (4) being able to ambulate for at least 10 m with or without an aid; (5) being free from neurological diseases; and (6) could arrange their own transport to a testing venue in their community. Before the study began, all participants gave written informed consent. All procedures performed in this study were anonymous and in accordance with the declaration of Helsinki, and were also approved by the ethical committee of the faculty of kinesiology, University of Zagreb, Croatia (ethical code number: 2019).

2.2. Peak Plantar Pressures

Peak plantar pressures were estimated by using a Zebris plantar pressure platform (FDM; GmbH, Munich, Germany; number of sensors: 11,264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm). The methodology and protocols for obtaining gait analysis data are described in detail elsewhere [20]. In brief, each participant was instructed to walk at a comfortable speed across the platform without shoes and socks. Additionally, all participants were required to look straight forward, not targeting the pressure platform. When they reached the end of the walkway, they needed to turn 180° around and continue to walk again over the platform. Finally, when they reached the end of the second walkway (trial), they again turned 180° around and walked a final time across the platform to the end of the walkway. After the completion of measurement, the software generated the data regarding peak plantar pressures beneath the different foot regions of forefoot, midfoot and hindfoot.

2.3. Physical Fitness Assessment

To assess the level of physical fitness, we used the senior fitness test [21]. The measurement protocols and the reliability and validity properties are described elsewhere [21]. We included seven tests in this study: (1) height and weight; (2) chair stand in 30 s; (3) arm curl in 30 s; (4) 2-min step test; (5) chair sit-and-reach test; (6) back scratch test; and (7) 8-foot up-and-go test. In addition, body-mass index was used as an indicator of general adiposity. The chair stand in 30 s test was used to assess lower body strength, and in it participants needed to come to a full stand from a seated position with arms folded across the chest. The arm curl in 30 s was the second test, representing a general measure of upper-body strength, and involved counting the number of times a person could curl a hand weight (5 pounds or 2.3 kg for women and 8 pounds or 3.6 kg for men) through a full range of motion. The third test included a person stepping in place and raising their knees to a height halfway between the patella (kneecap) and iliac crest (front hip bone). This test is a measure of aerobic endurance, and the results were expressed in the number of steps taken during the two minutes. Next, the chair sit-and-reach test aimed to assess lower-body flexibility. The test involved sitting at the front edge of a stable chair with one leg extended and the other foot flat on the floor. With hands on top of each other and arms outstretched, the participant reached as far forward as possible toward the toes. The score was expressed in cm (a higher score was better) and was measured three times, where the best score was taken in the model. The purpose of the back-scratch test was to assess upper-body flexibility, particularly shoulder flexibility. The test involved reaching one hand over the shoulder and down the back as far as possible and the other hand around the waist and up the middle of the back as far as possible, trying to bring the fingers of both hands together. The score was expressed in cm (a higher score was better) and was measured three times, where the best score was taken in the model. Finally, the 8-foot up-and-go test was used to assess agility and dynamic balance. The test involved getting up from a seated position and walking as quickly as possible around a cone that is 8 feet (2.4 m) away and returning to the seated position. The test was performed two times and the results were expressed in seconds. Height and weight were objectively measured.

3. Covariates

We used the downtown fall risk index to assess the risk of falls [22], which is a reliable and valid instrument that measures five modules: previous falls, medication, sensory deficits, mental state and gait. The results are then summarized and give the score between 0 and 11. A higher score indicates higher risk of falls [22]. Presence of foot pain was determined by using the same question as in previous studies: "On most days do you have pain, aching, or stiffness in either of your feet?" [23]. Responses were categorized as: "Yes, pain in one foot", "Yes, pain in both feet", "Yes, but unable to detect the side" and "No, no pain in either foot". Finally, the responses "Yes, pain in one foot", "Yes, pain in both feet'" and "Yes, but unable to detect the side" were collapsed into the "foot pain" category vs. the "no foot pain" category. In addition, we asked each participant about their chronological age.

4. Data Analysis

Basic descriptive statistics are presented as mean ± SD or median (25th–75th percentile range) for normally and non-normally distributed variables. Lastly, the presence of foot pain is presented as the percentage. We calculated z-scores for each physical fitness test. To get an overall physical fitness index, we summed all z-scores. To calculate the associations between the level of physical fitness (separate components and overall physical fitness index) and peak plantar pressures beneath the different foot regions (forefoot, midfoot and hindfoot), we used generalized estimating equations with a linear regression model. For each analysis, we calculated unadjusted (model 1) and adjusted (model 2) associations. The associations in model 2 were adjusted for the risk of falls, the presence of foot pain and chronological age. The results are presented as β coefficients with 95% confidence intervals. All analyses were performed in the Statistical Packages for Social Sciences version 23 (SPSS Inc., Chicago, IL, USA) with a statistical significance of $p \leq 0.05$.

5. Results

Basic descriptive statistics of the study participants are presented in Table 1.

Table 1. Basic descriptive statistics of the study participants ($N = 120$).

Study Variables	Mean ± SD
Age (years)	71.01 ± 6.77
Height (cm)	158.92 ± 21.41
Weight (kg)	70.29 ± 12.97
Peak plantar pressure beneath the forefoot (N/cm^2)	46.73 ± 10.65
Peak plantar pressure beneath the midfoot (N/cm^2)	16.94 ± 7.41
Peak plantar pressure beneath the hindfoot (N/cm^2)	31.57 ± 7.44
Body-mass index (kg/m^2)	26.79 ± 4.42
Chair stand in 30 s (#)	16.53 ± 4.14
Arm curl in 30 s (#)	19.35 ± 4.68
2-min step test (#)	170.36 ± 43.70
Chair sit–and-reach test (cm) *	7.00 (1.00–11.00)
Back scratch test (cm) *	0.75 (−7.75–4.00)
8 feet up–and-go test (s)	5.37 ± 0.96
Downtown Fall Risk Index *	2.00 (1.00–3.00)
Foot pain (% of "Yes" response) **	54.2

* denotes using median (25th–75th percentile range); ** denotes using percentages; # denotes using the number of repetitions.

The associations between physical fitness and peak plantar pressures under the forefoot region are presented in Table 2. All physical fitness tests were significantly and inversely associated with forefoot peak plantar pressure, except for waist circumference and the back scratch test. In a model adjusted for age, the risk of falls and the presence of foot pain, similar significant and inverse associations remained, excluding the back scratch test and chair sit-and-reach test.

Table 2. The associations between separate components and physical fitness index and peak plantar pressure beneath the forefoot region of the foot in older women ($N = 120$).

Study Variables	Model 1			Model 2 *		
	β Coefficient	95% CI	p-Value	β Coefficient	95% CI	p-Value
Body-mass index	0.11	−0.29 to 0.56	0.576	0.19	−0.18 to 0.66	0.354
Chair stand in 30 s	−1.22	−1.65 to −0.79	<0.001	−1.02	−1.53 to −0.50	<0.001
Arm curl in 30 s	−1.04	−1.33 to −0.75	<0.001	−0.87	−1.20 to −0.53	<0.001
2-min step test	−0.11	−0.14 to −0.08	<0.001	−0.09	−0.12 to −0.05	<0.001
Chair sit-and-reach test	−0.33	−0.54 to −0.12	0.002	−0.18	−0.41 to −0.05	0.130
Back scratch test	−0.13	−0.32 to 0.07	0.198	0.01	−0.18 to 0.21	0.895
8 feet up-and-go test	3.14	1.17 to 5.11	0.002	2.22	0.08 to 4.35	0.042
Physical fitness index	−1.84	−2.31 to −1.37	<0.001	−1.75	−2.42 to −1.08	<0.001

* adjusted for age, the risk of falls and foot pain. $p < 0.05$.

Table 3 shows the associations between physical fitness and peak plantar pressures under the midfoot region. Specifically, all physical fitness components were significantly and inversely associated with the midfoot peak plantar pressure, except for the 2-min step test and 8 feet up-and-go test. In model 2, the arm curl in 30 s, 2-min step test and 8 feet up-and-go test were not significantly associated with midfoot peak plantar pressure.

Table 3. The associations between separate components and physical fitness index and peak plantar pressure beneath the midfoot region of the foot in older women ($N = 120$).

Study Variables	Model 1			Model 2 *		
	β Coefficient	95% CI	p-Value	β Coefficient	95% CI	p-Value
Body-mass index	0.37	0.13 to 0.68	0.007	0.39	016 to 0.71	0.006
Chair stand in 30 s	−0.62	−0.94 to −0.30	<0.001	−0.57	−0.88 to −0.25	<0.001
Arm curl in 30 s	−0.38	−0.76 to −0.01	0.046	−0.30	−0.71 to 0.10	0.143
2-min step test	−0.03	−0.06 to 0.01	0.081	−0.01	−0.05 to 0.02	0.354
Chair sit-and-reach test	−0.19	−0.31 to −0.07	0.002	−0.14	−0.28 to −0.01	0.036
Back scratch test	−0.22	−0.37 to −0.08	0.003	−0.19	−0.31 to −0.06	0.004
8 feet up-and-go test	1.09	−0.28 to 2.45	0.120	0.82	−0.63 to 2.27	0.266
Physical fitness index	−0.84	−1.44 to −0.24	0.006	−0.90	−1.62 to −0.17	0.015

* adjusted for age, the risk of falls and foot pain. $p < 0.05$.

Finally, Table 4 shows the associations between physical fitness and peak plantar pressures under the hindfoot region. All physical fitness tests were significantly and inversely associated with the hindfoot peak plantar pressure, excluding waist circumference and the back scratch test. In the adjusted model, only the chair stand in 30 s, chair sit-and-reach test and physical fitness index were significantly and inversely associated with the peak plantar pressure beneath the hindfoot region of the foot.

Table 4. The associations between separate components and physical fitness index and peak plantar pressure beneath the hindfoot region of the foot in older women ($N = 120$).

Study Variables	Model 1			Model 2 *		
	β Coefficient	95% CI	p-Value	β Coefficient	95% CI	p-Value
Body-mass index	−0.17	−0.53 to 0.15	0.316	−0.15	−0.53 to 0.20	0.422
Chair stand in 30 s	−0.48	−0.67 to −0.28	<0.001	−0.34	−0.60 to −0.08	0.011
Arm curl in 30 s	−0.31	−0.57 to −0.05	0.021	−0.13	−0.47 to 0.21	0.448
2-min step test	−0.03	−0.06 to −0.01	0.046	−0.01	−0.05 to 0.02	0.486
Chair sit-and-reach test	−0.26	−0.36 to −0.16	<0.001	−0.20	−0.31 to −0.09	<0.001
Back scratch test	−0.11	−0.27 to 0.06	0.206	−0.04	−0.18 to 0.11	0.622
8 feet up-and-go test	1.46	0.01 to 2.92	0.048	0.96	−0.48 to 2.39	0.191
Physical fitness index	−0.97	−1.23 to −0.71	<0.001	−0.93	−1.48 to 0.37	<0.001

* adjusted for age, the risk of falls and foot pain. $p < 0.05$.

6. Discussion

The main purpose of the study was to explore whether higher physical fitness levels were associated with lower peak plantar pressures in a sample of community-dwelling older adults. Our main findings are: (1) higher levels of the physical fitness components are associated with lower peak plantar pressures beneath the different foot regions; (2) a higher level of physical fitness index is associated with lower peak plantar pressures beneath the different foot regions; and (3) when the model is adjusted for potential covariates, similar associations between physical fitness and peak plantar pressures remained.

In our study, the overall physical fitness index may serve as a multifactorial component associated with peak plantar pressure, followed by the chair stand in 30 s and arm curl in 30 s tests. Previous evidence has shown that lower muscle masses of upper and lower extremities serve as significant predictors of foot function, including higher prevalence of foot pain and pronation [23]. Moreover, it has been documented that greater fat content in the muscle may lead to diseases associated with poorer physical performance and foot function [24]. One previous study has shown that higher peak plantar pressure beneath the hindfoot and midfoot areas of the foot are associated with lower balance test scores, indicating that proprioception and foot stability are important for predicting foot pressure [14]. Other studies have presented the associations between the level of physical activity and peak plantar pressure in children [15]. Specifically, a study by Mickle et al. [15] has shown that higher total physical activity level and time spent in moderate- to vigorous-intensity physical activity are correlated with lower peak pressures across the heel in boys, while no significant correlations between the aforementioned variables in girls were observed. Another study has shown that higher levels of moderate-intensity, vigorous-intensity and moderate- to vigorous-intensity physical activity are significantly correlated with peak plantar pressures beneath the middle and lateral forefoot regions of the foot, while vigorous-intensity physical activity is only correlated with lateral midfoot region [16]. In adults, higher levels of plantar pressures, especially in the lateral aspect, have been associated with discomfort during walking [13]. Therefore, we speculate that older adults who experienced certain discomfort in the foot region were discouraged from being physically active. Indeed, we strengthened our associations by adjusting for several potential covariates, including previously used question to assess the presence of foot pain [25], and still obtained similar associations between physical fitness and peak plantar pressures. We also found that the participants generated their highest pressures beneath the forefoot and the hindfoot regions. Since the hindfoot region is the first part of the foot to contact the ground during walking and the forefoot region is the last part of the push-off phase, higher plantar pressures seem to occur in those regions more frequently [15,16].

Previous studies have shown that older adults have significant foot deviations, including flatter feet, intrinsic foot muscle weakness, altered plantar pressure loading patterns during walking and reduced plantar tactile sensitivity [12]. Such conditions may alternatively lead to pain, discomfort and higher plantar pressures. Moreover, evidence has also shown that higher cognitive processes that modulate behavior, like attention and executive function, significantly decline with age, affecting normal walking and increasing the risk for falls [26].

It has been well-documented that physical functioning is a powerful preventing factor of a number of health conditions in a population of older adults [27]. However, only one fourth of older adults meet the recommended levels of physical activity prescribed by the World Health Organization [28]. Special interventions and health-related policies designed to increase the level of physical activity and fitness through health professionals or friends and family should be implemented within the community where they live.

This study has several limitations. First, a cross-sectional design cannot allow us to conclude about the causality of the association, that is whether lower levels of peak plantar pressures led to higher levels of physical fitness or vice versa. Second, a small sample might have underpowered the associations. Third, we based our study on a sample living in the urban part of the country, speaking Croatian and only of the white race. Fourth, we studied relatively healthy older women and the associations between the level of physical fitness and peak plantar pressures might be differently relevant for less healthy older adults. Fifth, our study only included women, and by including men, correlations might have been different, and we could make the generalizability for both sexes. Finally, we did not collect additional information regarding lifestyle factors, which may mediate or moderate the associations between physical fitness and peak plantar pressure in older individuals. Therefore, the aforementioned limitations should be overcome in future studies aiming to detect the associations between physical fitness and plantar pressure in older adults.

7. Conclusions

Our study shows that higher levels of physical fitness are associated with lower peak plantar pressures beneath the different foot regions of the foot in older women. Although a cross-sectional design of the study has been acknowledged as a limitation, our findings suggest that higher physical fitness level may be a significant predictor of peak plantar pressures among community-dwelling older women.

Author Contributions: Conceptualization, L.Š. and M.K.; data curation, L.Š.; formal analysis, L.Š.; funding acquisition, M.K.; investigation, L.Š.; methodology, L.Š. and M.K.; project administration, M.K.; resources, M.K.; Software, L.Š.; supervision, M.K.; validation, L.Š.; visualization, L.Š.; writing—original draft, L.Š., M.K. and M.Z.; writing—review and editing, L.Š., M.K. and M.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We would like to thank all the participants for their enthusiastic participation in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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