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Sex-specific associations among total bone-specific physical activity score, aortic parameters, and body composition in healthy young adults

SoJung Kim [a, *], Harshvardhan Singh [b]

[a] Department of Health and Exercise Science, School of Nursing & Health Professions, Rowan University, Glassboro, NJ, 08028, USA
[b] Department of Physical Therapy, University of Alabama, 1716 9th Avenue South, Birmingham, AL, 35294, USA

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ABSTRACT

Background/Objective: Physical inactivity is one of the major cardiovascular disease risk factors; however, not much is known regarding lifetime bone-specific physical activity and arterial stiffness. The aim of this cross-sectional study was to determine whether total bone-specific physical activity score (tBPAQ) was related to arterial stiffness and body composition in healthy young adults.

Methods: Healthy young women ($n = 56$, 20.3 ± 1.3 years) and men ($n = 52$, 21.0 ± 1.2 years) between 18 and 25 years were recruited for this study. The tBPAQ was used to obtain a comprehensive account of lifetime bone-loading physical activity. We measured the carotid to femoral pulse wave velocity (cfPWV) to evaluate arterial stiffness using the novel oscillometric device (SphygmoCor XCEL). Dual energy X-ray absorptiometry was used to measure bone free lean body mass (BFLBM, kg) and % total body fat.

Results: Partial correlations analyses showed a significant inverse relationship between tBPAQ and cfPWV ($r = -0.371$, $p = 0.007$) in young women; however, this relationship was not found in young men ($p > 0.05$). There were significant negative correlations between tBPAQ and % total body fat in both young women ($r = -0.265$, $p = 0.048$) and men ($r = -0.327$, $p = 0.018$). No significant relationships were found between tBPAQ and BFLBM ($p > 0.05$).

Conclusion: Our study provides preliminary evidence of sex-specificity of negative relationships of tBPAQ with i) cfPWV (women only) and ii) % total body fat (men and women). Whether bone-loading physical activity can lead to better cardiometabolic outcomes needs to be examined.

1. Introduction

Higher arterial stiffness is strongly linked to the later development of incident hypertension[1] as well as is an independent risk factor for future cardiovascular diseases.[2] Pulse wave velocity (PWV, m/s) is a well-accepted technique to measure arterial stiffness and is considered the gold standard method to evaluate the CV risk, vascular adaptation, and therapeutic efficacy of the treatment approach.[3] Generally, lower values of PWV are associated with a lower risk of heart attacks and strokes.[2] Notably, age-specific reference values of PWV have been well-established in various populations.[3–5] Numerous human studies have indicated that lifestyle modification such as higher levels of habitual physical activity can reverse arterial stiffness. Moreover, habitual physical activity can prevent the development of or delay the onset of arterial stiffness later in life.[6,7]

Physical inactivity is one of the major cardiovascular disease risk factors.[8] Inverse relationships between physical activity levels and arterial stiffness have been observed in children,[7,9] young adults[10] and older adults.[11–13] Studies using objective methods (e.g., accelerometer) reported that physical activity was inversely related to PWV in pre-pubertal children,[14] young[10] and old adults.[15] Conventionally, physical activity questionnaires based on metabolic equivalent cost have been used in previous works to support the idea that physical activity is a positive determinant of arterial health. For example, several cross-sectional studies have used self-reported physical activity questionnaires (e.g., International

* Corresponding author. Department of Health and Exercise Science, School of Nursing & Health Professions, Rowan University, 201 Mullica Hill Rd, Glassboro, NJ, 08028, USA.

E-mail addresses: kims@rowan.edu (S. Kim), hsingh@uab.edu (H. Singh).

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Physical Activity Questionnaire and Baecke Questionnaire),[9,13,16,17] suggesting that high levels of physical activity and aerobic exercise training are associated with reduced arterial stiffness. There is some emerging evidence that physical activity level assessed via bone-specific physical activity questionnaire (BPAQ), which uses ground reaction force (GRF)-derived loading values to determine the magnitude of physical activity, can be used as a marker of cardiovascular health. Specifically, the current BPAQ score, which reflects bone-loading physical activity over the previous year, has been shown to be negatively associated with mean arterial pressure, waist-to-hip ratio, triglycerides, and total cholesterol level.[18]

Among BPAQ scores, total BPAQ (tBPAQ) reflects a comprehensive account of lifetime bone-loading physical activity. It is important to understand the relationship between lifetime bone-specific physical activity and arterial stiffness, specifically in young adults, as it could provide a deeper insight into the interplay of impact-based physical activity and arterial health at an earlier stage of life. Further, knowledge of the relationship between BPAQ score and arterial stiffness could inform rehabilitation professionals on exercise techniques for improving cardiometabolic or cardiovascular health. Notably, not much is known regarding sex-specific relationships between tBPAQ scores and arterial stiffness. Clinically, a high % total body fat is a vital risk factor of arterial stiffness in young individuals.[19–21] A recent study showed tBPAQ was related to adiposity only in older women but not in men[22]; however, to our knowledge limited data exists if it holds true in young adults. Further, some knowledge on sex-specific associations between body composition and BPAQ can be useful for professionals and therapists working with weight loss programs and, musculoskeletal and cardiovascular rehabilitation. Therefore, the aim of this cross-sectional study was to determine whether tBPAQ scores are related to aortic parameters in healthy young adults. Another aim of this study was to investigate if tBPAQ scores are related to % total body fat. We hypothesized that tBPAQ scores would be inversely associated with PWV, which is a surrogate marker of arterial stiffness and % total body fat in healthy young adults. Also, we hypothesized that these significant relationships would be consistently found in young women and men.

2. Methods

2.1. Participants

Healthy young women (n = 56) and men (n = 52) between the ages of 18 and 25 years volunteered to participate in the study. Participants who were outside of the 18–25 years age range and who exceeded the weight limit of the DXA (136.1 kg) were excluded from the study. We used a pre-participation screening questionnaire if participants were free of cardiovascular diseases and not taking any medications that affect the cardiovascular system. In order to minimize exposure to ionizing radiation, participants who had received more than two X-ray examinations or had radiation treatment in the previous 12 months were excluded. Based on screening, female participants who may be pregnant or were pregnant were excluded from this study. The University's Institutional Review Board approved this study, and all participants gave written informed consent before the testing.

2.2. Anthropometry and body composition

Standing height (cm) was assessed using stretch stature (Detecto 439) to the nearest 0.1 cm, and body mass was measured on a calibrated electronic scale (Tanita 679) to the nearest 0.1 kg, respectively. We used the Hologic QDR 45000W bone densitometer (Hologic Discovery Wi, 12.1 version) to assess the body composition of the whole body. A certified DXA technician acquired and analyzed all DXA scans following standard manufacture's procedures. We obtained bone-free lean body mass (BFLBM, kg), fat mass (kg), and percent (%) total body fat from a whole-body DXA scan. In addition, a menstrual history questionnaire was used to determine if the female participant was pregnant.

2.3. Bone-loading physical activity

The BPAQ consisted of three independent sections: the past period (pBPAQ, from one year of age to the current age), the current period (cBPAQ, previous 12 months), and the total period (tBPAQ, average of pBPAQ and cBPAQ). The tBPAQ was calculated as the average of pBAPQ and cBPAQ scores using an online BPAQ calculator (www.fithdysign.com/BPAQ/), and algorithms used to analyze BPAQ responses have been described elsewhere.[23] In order to minimize recall errors, all participants were instructed to be as specific as possible with the activities they performed. Qualified researchers administrated and reviewed the questionnaire with each participant to ensure correct activity and frequency had been recorded.

2.4. Aortic parameters

Participants fasted for at least 8 h to avoid diurnal variation in the cardiovascular variables. Participants were rested in a supine position for at least 5 min prior to the testing. A trained investigator selected the appropriate supplied cuff (adult, 22–33 cm; large adult, 31–40 cm; Thigh, 38–50 cm) and placed on the participant's bare upper right arm. Brachial blood pressure was measured using a non-invasive and valid SphygmoCor XCEL device (AtCor Medical, Australia, V1.3) and used to calibrate the acquired waveform.[24] The participant remained in the same position and refrained from talking throughout the assessment. Three recordings were averaged to calculate the aBP (aortic systolic pressure), aDP (aortic diastolic pressure), and MAP (mean arterial pressure) parameters. The carotid to femoral Pulse Wave Velocity (cfPWV) was assessed to measure arterial stiffness using the same device. The femoral cuff was placed around the upper thigh as high up on the leg as comfortable per the participant. The same trained investigator measured the shortest distance from the supra-sternal notch directly to the top of the thigh cuff and supra-sternal notch to the carotid pulse using a non-stretchable tape. Applanation tonometry was used to record carotid pressure waveforms. The tonometer was placed directly on the top of the skin at the previously marked site of the strongest pulse in the participant's neck. Arterial stiffness measurements were performed in duplicate. If the two cfPWV values differed by more than 0.5 m/s, a third measurement was performed, and the median value was used. To ensure validity and reproducibility, Quality Control was checked by the trained investigator.

2.5. Statistical analyses

We performed all analyses using SPSS for Mac version 24 (SPSS Inc., Chicago, IL, USA), and data are reported as mean ± SD. We compared descriptive characteristics between male and female participants using Student's t-tests for continuous variables and Pearson's chi-squared tests for categorical variables. Partial correlation (adjusted for relevant covariates: age, BMI, BFLBM, current smoking) analyses were used to determine the relationships between tBPAQ and aortic parameters in young women and young men separately. Pearson's correlations tests were used to identify relationships between tBPAQ and body composition. We set the level of significance at $p < 0.05$.

3. Results

Descriptive characteristics of the study population are displayed in Table 1. Student's t-tests revealed that young men were older (0.7 years), taller (14 cm) and had greater BFLBM (16 kg) than young women ($p < 0.01$). Young women had greater fat mass (4.6 kg), % total body fat (10.3%) and lower aSP (4.3 mmHg) than young men ($p < 0.05$). Fig. 1 shows that cfPWV was significantly lower (0.5 m/s) in young women than in young men ($p = 0.002$). There were no significant differences in BMI, current smoking, tBPAQ, aDP and MAP between young women and young men ($p > 0.05$).

Partial correlation analyses indicated that there was a negative association between tBPAQ and arterial stiffness in the whole cohort ($r = -0.196$, $p = 0.046$). The cfPWV was inversely correlated with tBPAQ in young women (r = - 0.371, p = 0.007) while no significant relationship was found in young men (r = 0.097, p = 0.512), after adjustment for age, BMI, BFLBM, and current smoking (Fig. 2). There were no significant correlations between tBPAQ and aortic parameters (aSP) both in young women and young men ($p > 0.05$). However, negative relationships were found between aortic parameters (aDP and MAP) and tBPAQ in young women (r = - 0.315, p = 0.023) and (r = - 0.300, p = 0.031), respectively after adjustment for relevant covariates such as age, BMI, BFLBM, and current smoking (Table 2).

Pearson's correlations indicated that there were negative associations between tBPAQ and fat mass (r = - 0.341, p = 0.013) and % total body fat (r = - 0.327, p = 0.018) in young men. In young women, a negative relationship was only observed between tBPAQ and % total body fat (r = - 0.265, p = 0.048). There were no significant associations between tBPAQ and BFLBM both in young women and young men ($p > 0.05$ for both) (Table 2).

4. Discussion

In the present study, we examined the sex-specific relationships among bone-loading physical activity history, estimated by tBPAQ, aortic parameters, and body composition in healthy college students. Our main finding was that independent of age, BMI, BFLBM, and current smoking status, the cfPWV was inversely correlated with tBPAQ in young women, but not in young men. Also, tBPAQ was negatively associated with % total body fat in both young women and young men.

Among physical activity questionnaires, it has been well established that BPAQ is a significant predictor of aBMD, but its relation to arterial stiffness is not known. Several investigators have reported osteoporosis and/or osteopenia and arterial stiffness as strong independent predictors of cardiovascular mortality.[25] Both

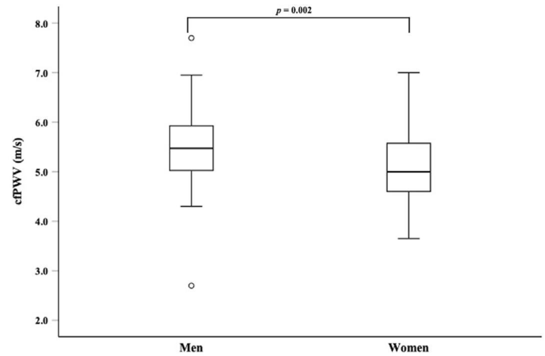

Fig. 1. Comparisons of cfPWV in young men and young women.

of these chronic conditions share common pathophysiological factors, including aging, smoking, low physical activity, and elevated BMI.[26,27] Research studies have shown a significant inverse correlation between PWV and aBMD in various populations.[25,28] Potential factors of this link might be explained by vascular calcifications found in patients with low aBMD[29,30] and the calcification of vessels that may lead to increase arterial stiffness.[31] Recently, inverse associations between cardiovascular disease risk factors (i.e., total cholesterol, waist-to-hip ratio, mean arterial pressure) and cBPAQ scores in the upper tertile (34 ± 13.3 years) were reported.[18] Our study extends these previous findings and found that tBPAQ was negatively associated with arterial stiffness as estimated by the cfPWV in the whole cohort (r = - 0.196). Interestingly, this relationship was found in young women (r = - 0.371), but not in young men (r = 0.095), after adjustment for age, BMI, BFLBM, and current smoking status. As previously documented in adolescents,[9] young,[17] and middle-aged adults,[32] we found that young men had stiffer arterial stiffness than young women (−0.5 m/s). These sex differences could be explained by several factors. First, our data showed systolic blood pressure in young women is lower than in young men ($p = 0.004$), which is one of the risk factors affecting arterial stiffness.[33] Second, although there was no statistically significant difference between genders with respect to tBPAQ (young women, 55.1 ± 32.2 vs. young men, 45.6 ± 21.6), this trend might affect our finding. Similarly, a longitudinal study showed that the increase in PWV was significantly larger in males than in female adolescents and this trend was associated with the decreased physical activity.[9]

In agreement with previous findings,[31,33,34] positive associations were found between aortic parameters (aSP, aDP, aMAP) and cfPWV in healthy college students (data not shown). In relation to bone-

Table 1
Descriptive Characteristics of the study population (mean ± SD).

	Total (n = 108)	Young women (n = 56)	Young men (n = 52)	Significance
Age (years)	20.6 ± 1.3	20.3 ± 1.3	21.0 ± 1.2	0.004
Height (cm)	170.5 ± 10.1	163.7 ± 7.6	177.7 ± 7.0	<0.001
Weight (kg)	71.1 ± 11.5	65.6 ± 10.8	77.1 ± 9.1	<0.001
BMI (kg/m^2)	24.4 ± 3.0	24.5 ± 3.7	24.4 ± 2.2	0.852
BFLBM (kg)	52.6 ± 11.0	44.9 ± 7.0	60.9 ± 8.1	<0.001
Fat mass (kg)	17.1 6.1	19.3 ± 6.4	14.7 ± 4.7	<0.001
% total body fat (%)	24.8 ± 8.0	29.7 ± 6.6	19.4 ± 5.5	<0.001
Current smoking (%)	19 (18%)	6 (11%)	13 (25%)	0.051
tBPAQ	50.5 ± 27.9	55.1 ± 32.2	45.6 ± 21.6	0.073
aSP (mmHg)	105.0 ± 7.7	102.9 ± 7.5	107.2 ± 7.5	0.004
aDP (mmHg)	67.7 ± 7.2	68.3 ± 7.0	67.0 ± 7.4	0.350
MAP (mmHg)	81.7 ± 8.2	82.3 ± 8.2	81.1 ± 8.1	0.457

SD: standard deviation, BMI: Body Mass Index, BFLBM: bone free lean body mass, tBPAQ: total bone specific physical activity score, aSP: aortic systolic pressure, aDP: aortic diastolic pressure, MAP: mean arterial pressure.

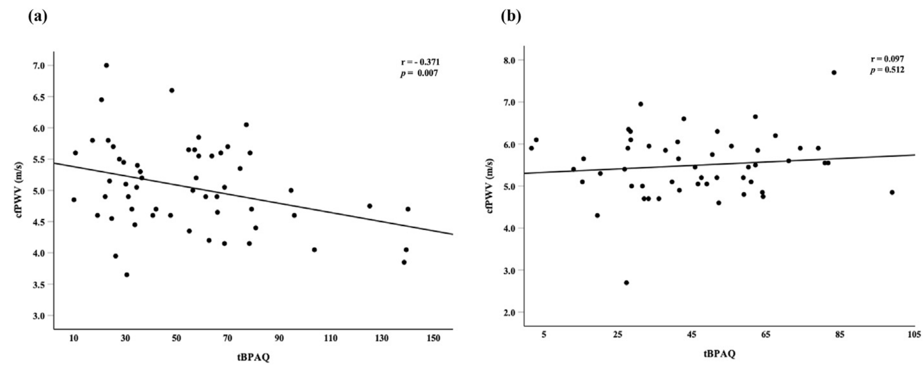

Fig. 2. Partial Correlations between cfPWV and tBPAQ in young women (a) and young men (b). All the relationships were adjusted for age, BMI, BFLBM, and current smoking.

Table 2
Correlations among tBPAQ, aortic parameters, and body composition in total, young women, and young men.

	Total (N = 108)		Young Women (n = 56)		Young Men (n = 52)	
	r	Significance	r	Significance	r	Significance
aSP (mmHg)	−0.155	0.115	−0.167	0.238	−0.015	0.920
aDP (mmHg)	−0.144	0.146	−0.315	0.023*	0.065	0.661
MAP (mmHg)	−0.158	0.109	−0.300	0.031*	0.075	0.612
BFLBM (kg)	−0.067	0.493	0.108	0.430	0.063	0.658
Fat mass (kg)	−0.155	0.108	−0.197	0.146	−0.341	0.013*
% total body fat (%)	−0.103	0.287	−0.265	0.048*	−0.327	0.018*

tBPAQ: total bone specific physical activity score, aSP: aortic systolic pressure, aDP: aortic diastolic pressure, MAP: mean arterial pressure, BFLBM: bone free lean body mass.
Partial correlations between tBPAQ and aortic parameters adjusted for age, body mass index, BFLBM, and current smoking.
Pearson's correlations between tBPAQ and body composition variables (BFLMB, fat mass, and % total body fat).

loading physical activity, we found no relationships between tBPAQ and aortic parameter (aSP, aMAP) both in young women and young men. In contrast, Weeks et al.[18] found that those in the upper tertile for cBPAQ showed lower MAP than those in the lower tertile in study participants (age 34.0 ± 13.3 years). This discrepancy may be due to different BPAQ scores used in data analyses. For the BPAQ, the participants were asked to fill out two independent sections. The past period (pBPAQ) constituted any activity reported from 1 year of age to 12 months previous to testing. The current period (cBPAQ) included any activity reported from the past 12 months, and the total period (tBPAQ) was calculated as the average of pBPAQ and cBPAQ scores. In the present study, we used the tBPAQ to investigate its overall lifetime impact on blood pressure. We found that there was a negative relationship between tBPAQ and aDP in young women ($r = -0.315$, $p = 0.023$), but not in young men. A negative relationship between tBPAQ and aDP could be due to multitude of factors. It has been well established that primarily endurance physical activity supplemented by resistance exercise is recommended to lower blood pressure in various populations.[35] Recently, evidence has shown that high-intensity interval training (HITT) could reduce blood pressure.[36] Although tBPAQ was not statistically different between women and men in our sample, the absolute value was higher in women. Thus, it can be postulated that high impact physical activity is especially useful for women. In future studies, lifestyle factors should be included to better understand this association.

This study was also aimed to investigate sex-specific relationships between bone-loading physical activity history and body composition variables. No significant relationships were found for BFLBM, but we found that there were negative associations between tBPAQ and % total body fat in both young women and men ($r = -0.265 \sim -0.327$; $p = 0.018–0.048$). Among body composition variables, researchers have found positive relationships between fat mass and arterial stiffness in children/adolescence[19,37] and until the age of 50 years.[38] Obesity is one of the major risk factors for cardiovascular disease, and our study suggests that bone-loading physical activity could potentially play a critical role in obesity management in young adults. This is clinically important because the rate of obesity in young adults has risen in recent years.[39] Moreover, the favorable relationship between tBPAQ and %total body fat could be potentially vital with respect to arterial stiffness later in life although we did not find significant relationships between % total body fat and arterial stiffness. Future studies should include key lifestyle factors such as sedentary time and dietary habits that affect fat mass as well as % total body fat.

There are several limitations to our study. First, our cross-sectional study design does not determine cause and effect relationships between variables. Second, the bone-loading physical activity was determined by a self-reported questionnaire. However, trained research assistants provided detailed exercise charts and checked once participants filled out the form. Finally, our study did not include cardiovascular risk factors such as cholesterol levels, diet habits, and sedentary time that could affect aortic parameters.

In conclusion, our study suggests that higher levels of bone-loading physical activity are associated with reduced arterial stiffness and % total body fat in healthy young adults. This knowledge can be useful for professionals and therapists working with cardiac rehabilitation and therapists working with weight loss programs. Longitudinal studies are needed to fully elucidate the underlying mechanisms and practical implications of these findings.

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CRediT authorship contribution statement

SoJung Kim: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Harshvardhan Singh:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – review & editing.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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