

11-2-2018

Taekwondo training reduces blood catecholamine levels and arterial stiffness in postmenopausal women with stage-2 hypertension: randomized clinical trial

Sang-Ho Lee

Steven D. Scott

Elizabeth J. Pekas

Seungyong Lee

Seok Hoon Lee

See next page for additional authors

Follow this and additional works at: <https://digitalcommons.unomaha.edu/hperfacpub>



Part of the [Health and Physical Education Commons](#), and the [Kinesiology Commons](#)

Please take our feedback survey at: https://unomaha.az1.qualtrics.com/jfe/form/SV_8cchtFmpDyGfBLE

Authors

Sang-Ho Lee, Steven D. Scott, Elizabeth J. Pekas, Seungyong Lee, Seok Hoon Lee, and Song-young Park

Taekwondo training reduces blood catecholamine levels and arterial stiffness in postmenopausal women with stage-2 hypertension: randomized clinical trial

Sang Ho Lee^a, Steven D. Scott^b, Elizabeth J. Pekas^b, Seungyong Lee^c, Seok Hoon Lee^d, and Song Young Park^{a,b}

^aDepartment of Taekwondo Mission, Kosin University, Busan, Korea;

^bSchool of Health and Kinesiology, University of Nebraska Omaha, Omaha, NE, USA;

^cDepartment of Kinesiology, University of Texas at Arlington, Arlington, TX, USA;

^dDepartment of Leisure & Sports Science, Dong-Eui University, Busan, Korea

To cite this article: Sang Ho Lee, Steven D. Scott, Elizabeth J. Pekas, Seungyong Lee, Seok Hoon Lee & Song Young Park (2019) Taekwondo training reduces blood catecholamine levels and arterial stiffness in postmenopausal women with stage-2 hypertension: randomized clinical trial, *Clinical and Experimental Hypertension*, 41:7, 675-681, DOI: <https://doi.org/10.1080/10641963.2018.1539093>

ABSTRACT

Objective: Menopause is associated with a progressive impairment of vascular function and muscular strength in women. Accordingly, the purpose of this study was to determine if Taekwondo training could improve blood catecholamine levels, arterial stiffness, blood pressure (BP) and skeletal muscle strength in postmenopausal women with stage-2 hypertension.

Methods: 20 postmenopausal women (70 ± 4 years old) with stage-2 hypertension were randomly assigned to a 1) Taekwondo training (TT; n = 10) or 2) Control (CON; n = 10) group. Taekwondo training was performed for 60 minutes/day, 3 days/week for 12-weeks.

Results: There were significant ($P < 0.05$) group by time interactions for resting epinephrine (EP) and norepinephrine (NE) levels, with EP decreasing in the TT group and NE increasing in the CON group. Additionally, brachial-ankle pulse wave velocity, resting heart rate, and BP were significantly decreased, while hand grip and leg strength were significantly increased in the TT group compared to CON group. **Conclusion:** These results suggest that Taekwondo training can be a novel and beneficial mode of exercise for improving cardiovascular function and muscular strength in this population.

Abbreviations: TT: Taekwondo training group; CON: control group; EP: epinephrine; NE: norepinephrine; ANS: autonomic nervous system; SNS: sympathetic nervous system; baPWV: brachial-ankle pulse wave velocity

KEYWORDS

Taekwondo; catecholamines; arterial stiffness; hypertension; Menopause

Introduction

Menopause is associated with an age-related increase in both blood catecholamine levels (1) and arterial stiffness (2) as well as a decrease in muscular strength (3), which can collectively contribute to an increased risk for cardiovascular disease (CVD) (4). This is of particular importance for postmenopausal women, as epidemiological studies have demonstrated that postmenopausal women have a greater risk for CVD than that of premenopausal women (5,6). Both age and menopause can increase blood catecholamine levels, specifically epinephrine (EP) and norepinephrine (NE), which is thought to result in attenuated autonomic nervous system (ANS) activity, as elderly and postmenopausal population have exhibited heightened sympathetic nervous system (SNS) activity at rest and a attenuated SNS response to exercise (7,8). This impaired ANS activity may play a role in the pathogenesis of CVD, as higher catecholamine levels have been observed in patients with CVD, such as older individuals with hypertension (9,10), including postmenopausal and hypertensive women (1).

Elevated pulse wave velocity (PWV), an index of arterial stiffness, is one of the major risk factors of atherosclerosis, hypertension and heart disease, and is commonly observed in post-menopausal women (11,12). In fact, an increase of only 1 m/s in PWV was found to be associated with a 12% increase in the risk of cardiovascular events in adults with high CVD risk (13). An elevated PWV is also associated with muscle mass and strength loss in older adults (14,15). Indeed, several studies have shown that sarcopenia is positively associated with PWV (16,17), and this relationship has been shown to be greater in elderly women than

in men (15). Moreover, muscle strength is believed to have a protective effect against arterial stiffness (14) and hypertension (18), which suggests that improvements in muscle strength could lead to cardio-vascular benefits and improved overall health.

Therefore, there is a need to reverse the increased blood catecholamine levels and arterial stiffness, as well as the reduced muscle strength and mass, experienced in post-menopausal women with hypertension. Exercise training has been utilized to reverse this attenuated cardiovascular and skeletal muscle function in post-menopausal women. Additionally, both aerobic and resistance exercise has been shown to protect against age-related cardiovascular disease risk factors, including increased blood catecholamine levels (19,20), arterial stiffness, high blood pressure and loss of muscle strength (21–24). Taekwondo may be a useful mode of exercise for this population, as it can be conducted at various intensities, incorporates both aerobic training components (i.e. jogging and running along with short rest periods between exercises) and resistance training components (constant ballistic movements and rapid muscular contractions utilizing body weight) and may improve strength, motor coordination, and cardiovascular health (25,26).

Additionally, Taekwondo is a commonly participated in self-defensive martial arts and exercise modality across the globe. For instance, according to the World Taekwondo Headquarters (Kukkiwon in Korea), currently more than eight million people in over 200 countries are practicing Taekwondo. This suggests that Taekwondo is an enjoyable exercise modality that many choose to participate in. Taekwondo is also typically performed in groups and under experienced supervision, which along with its enjoyability, may help to remove several perceived barriers to exercise, leading to an increase in exercise program adherence in this population. However, there are no studies to our knowledge that examine the effects of Taekwondo training on these parameters in postmenopausal women with stage-2 hypertension. Thus, the purpose of this study was to examine the effects of a 12-week Taekwondo training program on blood catecholamine levels, arterial stiffness, blood pressure and muscular strength in postmenopausal women with stage-2 hypertension.

Methods

Subject characteristics

All procedures employed in this study were conducted and performed according to the protocols approved by Kosin University's Institutional Research Board (KU IRB 2015–0019) and carried out in accordance with the Declaration of Helsinki. This study was also registered with clinicaltrials.gov (NCT03544307). Twenty postmenopausal, stage-2 hypertensive women (70 ± 4 years old; systolic BP > 140 and/or diastolic BP > 90) were recruited for this study and informed consent was obtained. Participants were screened by physicians of Kosin University and excluded if participants were obese (body mass index > 30 kg/m²), smokers, had heart disease, renal disease, psychiatric conditions as assessed by medical history, and/or taking any medications or hormone therapy in the year before the study. In addition, all participants were sedentary (< 1 h of regular exercise per week in the previous year). Subjects were randomly divided into two groups: 1) Taekwondo training (TT, $n = 10$) and 2) Control (CON, $n = 10$), and allocation was determined randomly, and sequencing was generated by computer-based number (Figure 1). Subject characteristics can be seen in Table 1. Measurements were obtained at baseline and at 12 weeks during the same time of the day (± 1 hour) in the morning and after an overnight fast. Subjects abstained from caffeinated drinks and alcohol between 48 and 72 hours before baseline testing and after the last exercise session. Cardiovascular measurements were collected in a quiet temperature-controlled room (22–24°C) after at least 10 minutes of rest in the supine position. Participants were instructed not to alter their regular lifestyle habits during the study period (verified through food/physical activity logs).

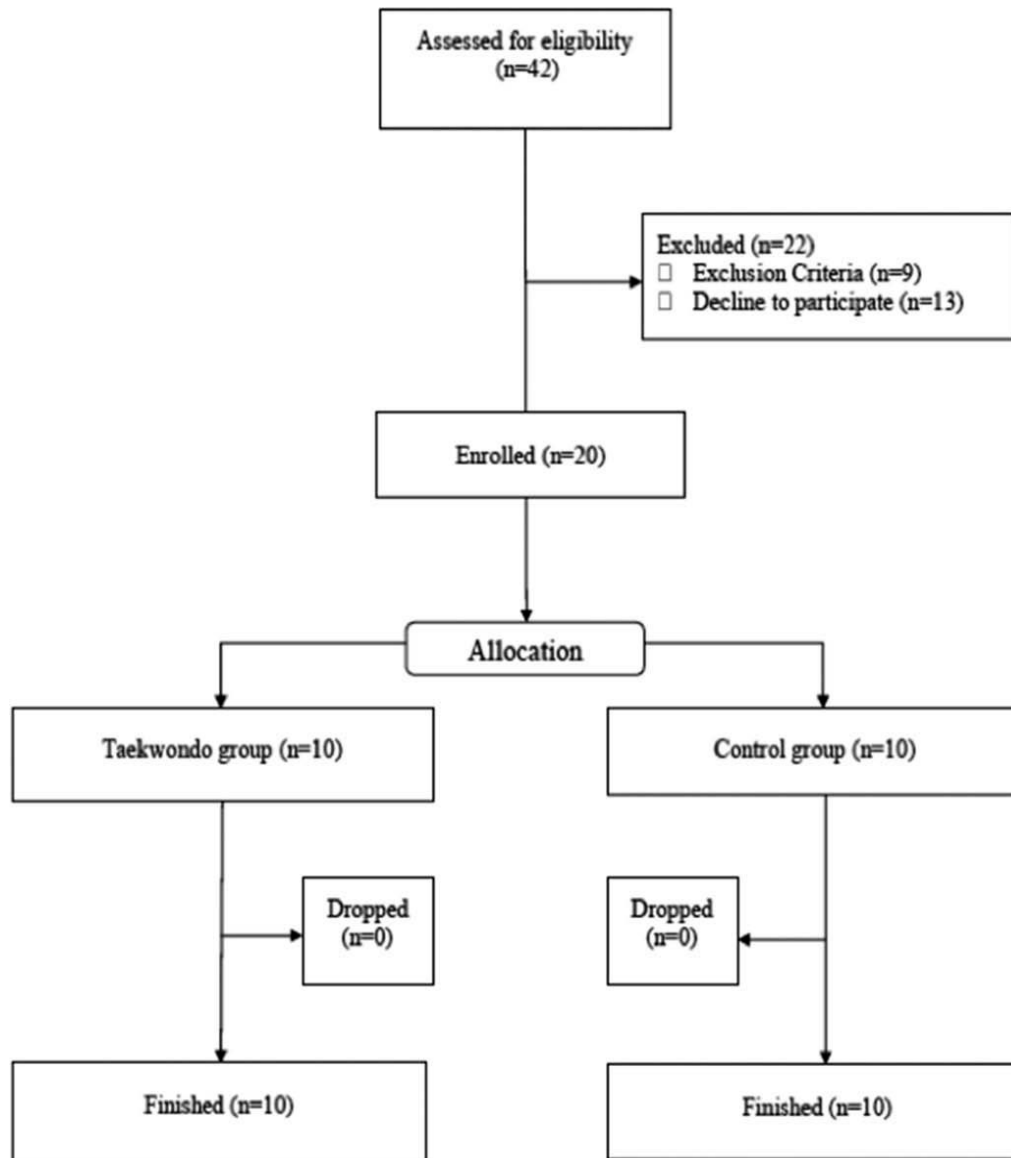


Figure 1. Diagram for the experimental study.

Taekwondo training program

According to the ACSM guidelines for exercise testing and prescription (27), the current investigation applied a 12-week Taekwondo training protocol of 3 times/week, 60 min/per session for the TT group. Exercise intensity was set at 30–40% heart rate reserve (HRR: maximum heart rate – resting heart rate) for the first four weeks and gradually increased up to 50–60% HRR during the last four weeks of training (Table 2). Heart rate was measured by Polar RS400 heart rate monitor (Polar Electro, Kempele, Finland) in order to monitor the exercise intensity. Subjects

reported to the training facility 3 time/week for two weeks prior to the baseline measures for familiarization with the experimental design and the Taekwondo instruction. During this period, subjects went through instruction for the Taekwondo training protocol and familiarized themselves with the 1 RM test for leg and hand grip strength. The participants in the CON group maintained their normal life without any manipulation but were present in the laboratory at the same frequency and duration of the TT group throughout the whole study.

Table 1. Physical characteristics of study participants.

Variables	CON (N= 10)			TT (N=10)			P-value	Cohen's d
Age (years)	70	±	4	70	±	4		
Height (cm)	154.1	±	6	155.1	±	4.7		
Weight (kg)								
Pre	60.4	±	6	60.4	±	6.4	*p = 0.023, †p = 0.031 ‡p=0.028	d = 0.31
Post	61	±	6.1	58	±	4.3*†		
Δ	1.2	±	0.2	-2.5	±	0.3‡		
BMI (kg/m2)								
Pre	25.4	±	3.4	25	±	1.6	*p = 0.037, †p = 0.034 ‡p = 0.034	d = 0.44
Post	25.5	±	2.6	25	±	2.1*†		
Δ	0.3	±	0.1	-1	±	0.3‡		
Heart Rate (bpm)								
Pre	69	±	4	69	±	5	*p = 0.013, †p = 0.021 ‡p = 0.033	d = 0.71
Post	69	±	5	65	±	4*†		
Δ	0	±	0.2	-4	±	1‡		
SBP (mmHg)								
Pre	143	±	2	144	±	2	*p = 0.031, †p = 0.027 ‡p = 0.017	d = 1.87
Post	142	±	2	130	±	2*†		
Δ	-1	±	1.2	-14	±	1.4‡		
DBP (mmHg)								
Pre	99	±	2	98	±	2	*p = 0.025, †p = 0.028 ‡p = 0.016	d = 1.83
Post	97	±	2	87	±	2*†		
Δ	-2	±	0.7	-10	±	1.7‡		
Hand Grip Strength (kg)								
Pre	25	±	4	24	±	4	*p = 0.033, †p = 0.041 ‡p = 0.016	d = 0.61
Post	24	±	4	27	±	3*†		
Δ	-1	±	0.3	3	±	0.8‡		
Leg Strength (kg)								
Pre	38	±	7	39	±	6	*p = 0.042, †p = 0.036 ‡p = 0.0	d = 0.81
Post	38	±	8	41	±	7*†		
Δ	0	±	0.6	2	±	0.8‡		

Values are Mean ± Standard Deviation

TT: Taekwondo training group, CON: Control group

BMI: Body Mass Index, SBP: Systolic Blood Pressure, DBP: Diastolic Blood Pressure

Pre: Baseline measures before Taekwondo training, Post: Measures after 12 weeks of Taekwondo training

* $P < 0.05$, different than pre

† $P < 0.05$, different than control

‡ $P < 0.05$, difference in delta between CON and TT

All subjects had Taekwondo training previously as part of their high school curriculum as well and Taekwondo training was supervised by trained Taekwondo masters. Subjects wore body protectors during the entirety of the training and no injuries were reported. Subjects began the training session with a dynamic stretching warm-up for 10 minutes. They then participated in Taekwondo training for 40-minutes. This consisted of time practicing Taekwondo kicks, punches, steps and step-sparring while facing an opponent (either an instructor or another participant). They then spent the remaining time practicing Taekwondo forms and then walked, jogged or ran, depending on what intensity was desired. A 10-minute, static stretching cool-down was applied after the 40-minute training session. A list of each exercise performed can be seen in Table 3. This training regimen consisted of both aerobic and anaerobic training, as many of the kicks, punches and steps are plyometric in nature, requiring jumps, half-squats, and lunges. These utilize dynamic and isometric muscle contractions using body weight, gravity and the opponent for resistance. Additionally, the short rest periods and walking, jogging and running contribute to the aerobic aspects of the training.

Table 2. Taekwondo training program progression.

Activity	Duration	Week	Intensity (%HRR)	Intensity (~bpm)	Frequency
Warm-up	10 min	1-12	-	-	3 times/week
Taekwondo Training Program	40min	1-4	30-40%	~96-104	3 times/week
		5-8	40-50%	~105-112	
		9-12	50-60%	~113-122	
Cool-down	10 min	1-12	-	-	3 times/week

Blood sampling

The subjects were asked to report to the laboratory fully rested and fasted from 8 pm the day before the blood sampling. 10 ml of blood were collected from the brachial vein using vacutainer and needle (Bom Medrea Co, LTD, Phnom Penh, Cambodia) by a trained phlebotomist before and after Taekwondo training. Blood serum was separated by centrifuge at 3,000 rpm for 10 minutes. Blood catecholamine levels of epinephrine and norepinephrine were analyzed in duplicate

by using commercially available ELISA kit (Abnova, Taipei City, Taiwan). Mean intra-assay coefficient variation was 2.8% for epinephrine and 3.2% for norepinephrine.

Table 3. Components of Taekwondo training.

Kicks	Punches	Steps	Step Sparring	Taekwondo Forms	Aerobic Training
Front kick	Reverse punch	Forward-back step	Tactical forward-back step	Palgwe	Walking
Round house kick	Jab	One-two step	Tactical one-two step	Taegeuk	Jogging
Side kick	Hook punch				Running
Axe kick	Upper cut				
Back kick	Back fist				
Turn-kick	Hammer fist				
Nara kick					

Arterial stiffness

Brachial-ankle pulse wave velocity (baPWV) was measured using non-invasive arterial tonometry with SphygmoCor (AtCor Medical, New South Wales, Australia) and analysis software (version 8.0, SphygmoCor Cardiovascular Management Suite) for measurement of baPWV(m/s), an indicator of arterial stiffness. Two measurements were collected at each time point and averaged as previously described (22,23).

Muscle strength

Leg muscle strength was assessed by the one repetition maximum (1RM) test using a leg extension machine (Cybex 6000; Lumex, Albertson, NY). Subjects were familiarized with the exercise and lifting technique during the two-week familiarization period. 1RM was measured on the dominant leg, which was achieved within five attempts. The 1RM was considered the highest weight lifted using the proper form. Handgrip muscle strength was measured on the dominant arm with the subject sitting in a straight-backed chair with feet placed flat on the floor, shoulder adducted and neutrally rotated, elbow flexed at 90° and the forearm and wrist in a neutral position. Handgrip muscle strength was determined as the highest of three maximal voluntary contractions using a handgrip dynamometer (Jamar, Bolingbrook, IL).

Statistical analysis

All parameters were normally distributed as shown by the Shapiro-Wilk test. Differences at baseline between groups were evaluated using unpaired t tests. Data were analyzed by SPSS statistical software (BM SPSS Analytics version 23.0; IBM, Armonk, NY). A two-way ANOVA with repeated measures [groups TT and CON] x time [before and after 12 weeks]) was used to determine the statistical significance of differences between pre-training and post-training. If significance was found, paired t-tests were used for *post hoc* comparisons. Independent samples t-test were also used to examine the baseline differences between the TT and CON groups. Additionally, correlation between variables were assessed with Pearson product-moment correlation. The significance was defined *a priori* as $P < 0.05$. We also performed an effect size analysis utilizing eta-squared (η^2) for the two-way ANOVA, interpreted 0.01, 0.06 and 0.14 as small, medium and large, respectively, and Cohen's d for the t-tests, interpreted as 0.20, 0.50 and 0.80 as small, medium and large, respectively. All data are presented as mean \pm standard deviation. G*Power 3.1 power analysis software (Universität Kiel, Germany) was used to determine the appropriate number of subjects. A power analysis calculation determined a minimum sample size of 20 (10 each group) would allow the observation of a difference of 3% to 5% between the group (TT vs CON) on the primary study outcome variable of baPWV with a power of 80%.

Results

Subject characteristics

Compliance to the TT training was >99%. There were no significant differences among age, height, weight, body mass index (BMI), resting heart rate (RHR), starting systolic and diastolic blood pressure (Pre-SBP and Pre-DBP) or starting hand-grip or leg strength between groups. There were significant ($P < 0.05$) group by time interactions between body weight, BMI, RHR, and resting SBP and DBP, which decreased in the TT group, and for hand grip and leg strength which increased in the TT group, compared to no change in the CON group (Table 1).

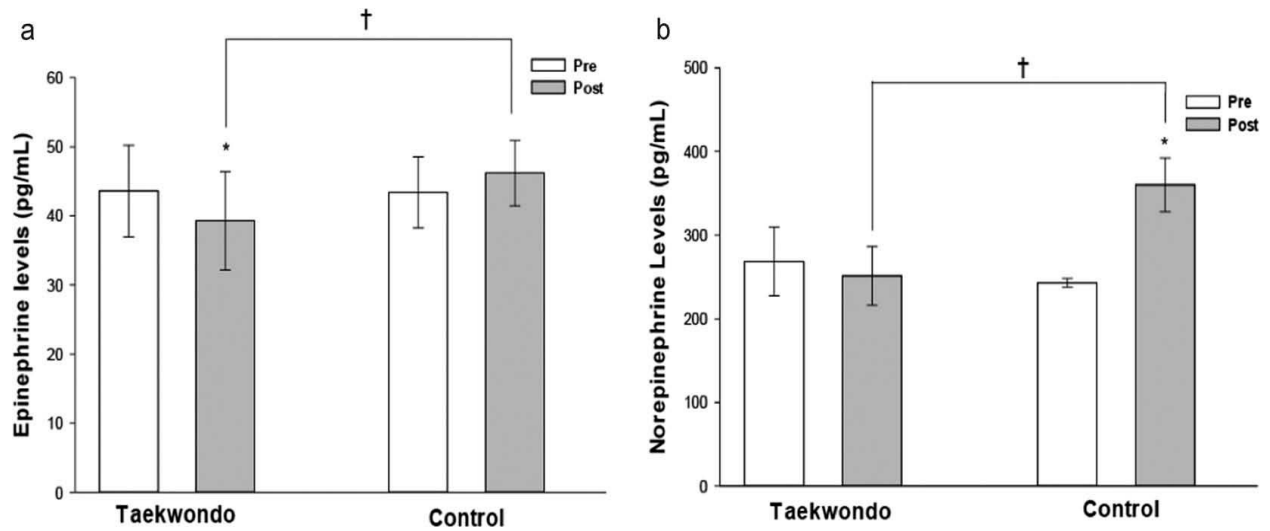


Figure 2. Changes in epinephrine (EP) and norepinephrine levels after 12-weeks of Taekwondo training (TT) compared to a control (CON). (A) EP levels decreased in the TT group and were lower than the control group after post-testing. (B) NE levels increased in the control group and were higher than the TT group after post-testing. (A). Effect size analysis: η^2 group: 0.06, time: 0.14, interactional: 0.05. (B). Effect size analysis: η^2 group: 0.06, time: 0.24, interactional: 0.07. * $P < 0.5$, different than pre, † $P < 0.5$, different than control

Changes in blood catecholamine levels

There were significant ($P < 0.05$) group by time interactions for EP levels, which decreased in the TT group and trended towards an increase in the CON group ($P = 0.07$) (Figure 2A), and for NE levels, which increased in the CON group with no change in the TT group (Figure 2B).

Changes in arterial stiffness

There was a significant ($P < 0.05$) group by time interactions in baPWV, which decreased in the TT group compared to no change in the CON group (Figure 3).

Changes in muscle strength

There was a moderate to strong correlation between and baPWV and both handgrip strength ($r = -0.6$) (Figure 4A) and leg strength ($r = -0.4$) (Figure 4B), with baPWV decreasing while both handgrip and leg strength increased ($P < 0.05$).

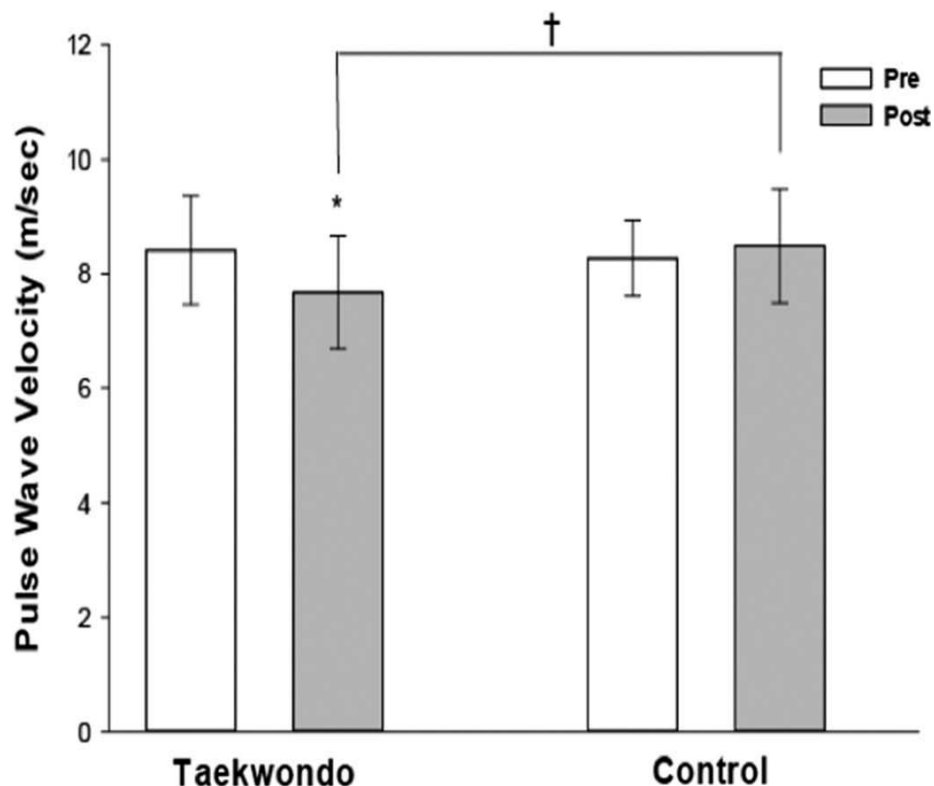


Figure 3. Changes in brachial-ankle pulse wave velocity (baPWV) after 12-weeks of Taekwondo training (TT). baPWV decreased in the TT group and was lower than the control group after post-testing. Effect size analysis: η^2 group: 0.05, time: 0.12, interactional: 0.08. * $P < 0.5$, different than pre, † $P < 0.5$, different than control

Discussion

The major findings from the study are that 12-weeks of Taekwondo training reduced the elevated blood catecholamine levels and arterial stiffness in post-menopausal women with stage-2 hypertension. In addition, we found that Taekwondo training was able to reduce RHR and SBP and DBP. Furthermore, Taekwondo training was able to increase both hand grip and leg strength, which have been shown to be inversely correlated with cardiovascular risks (15–17). To our knowledge, this is the first study to examine the beneficial effects of Taekwondo as a non-pharmacological therapeutic method to improve both cardiovascular health and muscular strength in post-menopausal women with stage-2 hypertension.

The blood catecholamines EP and NE have been shown to be elevated in women when compared to men (7), as well as in elderly (28), sedentary (20) and hypertensive populations (9,10). These elevated blood catecholamine levels can be detrimental and have often been reported with a concomitant attenuation of the autonomic nervous system, leading to cardiovascular dysfunction and poor overall health (10). Several mechanisms for the increase in these levels have been proposed. One often proposed mechanism has been an age-related decrease in blood catecholamine clearance after stress (29,30). However, research has shown that resting catecholamine clearance does not change with aging (31). A more likely mechanism suggested for this increase in blood catecholamine levels is a decline in sympathetic nervous system sensitivity, possibly due to a loss in sensitivity of either the adrenal medulla glands or beta-adrenergic receptors, which up-regulate catecholamine levels (32).

Although the mechanism(s) underlying the menopausal-and hypertension-induced increase in EP and NE levels is not entirely understood, exercise is known to reduce these levels and/or improve sensitivity and thus improve autonomic nervous system function (7). For instance, exercise trained elderly subjects were

found to have similar catecholamine levels when compared to untrained younger subjects (19). Additionally, trained elderly distance runners were shown to have similar blood catecholamine levels to one hour of maximal exercise as younger trained counterparts (20). Our findings are well aligned with these results, as a 12-week Taekwondo training regimen was able to reduce resting EP levels and prevent the typical increased NE levels seen in this population without training.

The results of this study also revealed the beneficial effects of Taekwondo training on measures of cardiovascular health, including both baPWV, a measure of arterial stiffness, and BP. This is of clinical significance, as increases in arterial stiffness have been shown to contribute to elevated BP, ultimately resulting in an increased risk for cardiovascular complications and mortality in postmenopausal women (11). Therefore, reducing both arterial stiffness and BP may decrease the incidence of CVD in this population (22). Indeed, epidemiological data has shown that in subjects with hypertension, an increase of only 1 m/s in baPWV was found to be associated with a 12% increase in the risk of cardiovascular events (13), and a 2 mmHg reduction in resting SBP can lead to a reduced mortality rate of 6% from stroke and of 4% from coronary heart disease (33). This study observed that Taekwondo training was able to reduce baPWV by 0.6 m/s and SBP and DBP by 14 and 11 mmHg respectively, revealing that Taekwondo training can be a clinically significant exercise modality for improving cardiovascular health in postmenopausal women with hypertension.

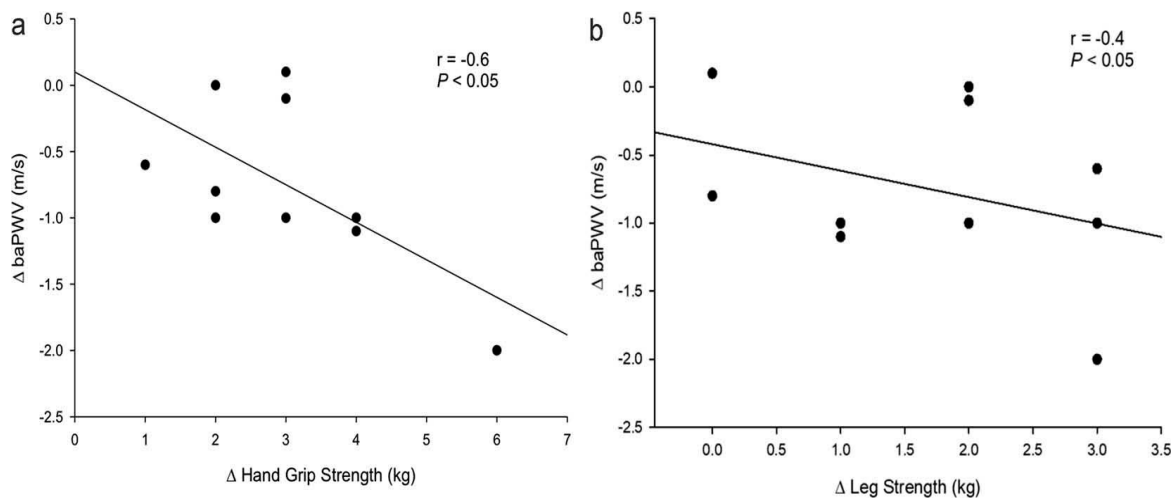


Figure 4. Relationship between the changes in brachial-ankle pulse wave velocity (baPWV) and (A) hand grip strength and (B) leg strength. Statistical significance was set at $P < 0.05$.

There have been several mechanisms proposed for the exercise-induced reductions in baPWV and BP similar to what was observed in this study. One potential mechanism responsible for these changes may be an exercise-induced increase in endothelial nitric oxide synthase activity, leading to a greater bioavailability of nitric oxide (NO), a potent vasodilator that is believed to play a role in reducing arterial stiffness (21). In fact, a reduced baPWV and an increase in circulating NO was observed in postmenopausal women after a 12-week stair climbing exercise intervention (34). Additionally, since we have shown that resting EP levels and HR reduced following Taekwondo training, an improvement in autonomic nervous system function may be another proposed mechanism for the reduced baPWV and BP in this study. This is supported by our previous research which has shown that a 12-week stair climbing intervention was able to reduce resting heart rate in postmenopausal women with stage-2 hypertension (21). Additionally, an 8-week moderate-intensity exercise intervention was shown to improve heart rate variability in sedentary postmenopausal women (35).

We found that hand grip and leg strength were also improved following Taekwondo training in this population. This is of importance, as an increased arterial stiffness, commonly observed in postmenopausal women with hypertension, can be associated with both the loss of muscle mass and strength (14). Our research showed that the relationship between handgrip and leg strength gain and reduction of baPWV following the Taekwondo training intervention was negatively correlated ($r = -0.6$ and -0.4 , respectively) (Figure 4), and this finding is well aligned with the previous findings of others (18,21,22). These results suggest that increased muscular strength has protective effects against the risks for cardiovascular disease. In fact, the findings that Taekwondo training increased hand grip strength and leg strength may carry clinical significance, as age-related losses in muscular strength have been observed in this population (16,17). Additionally, we have previously shown that combined aerobic and resistance exercise training may have better effects on improved arterial stiffness, BP and muscular strength in postmenopausal women with hypertension (21– 23) compared to either aerobic only or resistance only exercise training. Taekwondo training

contains both aerobic and anaerobic components and therefore may be a useful exercise modality to improve cardiovascular health in postmenopausal women.

Conclusion

These findings reveal that Taekwondo training is an effective therapeutic method for improving blood catecholamine levels, arterial stiffness, blood pressure and muscular strength in postmenopausal women with stage-2 hypertension. Thus, these results support the use and recommendation of this form of exercise training for the prevention and treatment of risks for cardiovascular disease in this population.

Acknowledgments

The authors would like to thank our participants.

Disclosure Statement

All authors declare no conflicts of interest.

Funding

There was no funding source for this study.

Data Availability

Please make any requests for data to the corresponding author.

Author Contributions

Authors' roles: Conception and design of the experiments: SHL and SHL. Collection, assembly, analysis and interpretation of data: SHL, SYL, SDS, SYP and SHL. Drafting the article or revising it critically for important intellectual content: SDS, SYP, EJP, SYL and SHL.

References

1. Villecco AS, de Aloysio D, Radi D, Sprovieri G, Bargossi AM, Grossi G, Gueli C,

- Salgarello M, Cavrini G. Plasma catecholamines in pre- and in postmenopausal women with mild to moderate essential hypertension. *J Hum Hypertens*. 1997;11(3):157–62.
2. Fleg JL, Morrell CH, Bos AG, Brant LJ, Talbot LA, Wright JG, Lakatta EG. Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation*. 2005;112(5):674–82. doi:10.1161/CIRCULATIONAHA.105.545459.
 3. Greeves JP, Cable NT, Reilly T, Kingsland C. Changes in muscle strength in women following the menopause: a longitudinal assessment of the efficacy of hormone replacement therapy. *Clin Sci (Lond)*. 1999;97(1):79–84.
 4. Ferrari AU, Radaelli A, Centola M. Invited review: aging and the cardiovascular system. *J Appl Physiol*. (1985) 2003;95(6):2591–97. doi:10.1152/jappphysiol.00601.2003.
 5. Vилlecco AS, de Aloysio D, de Liberali E, Ferrari G, Mauloni M. High blood pressure and 'ischaemic' ECG patterns in climacteric women. *Maturitas*. 1985;7(2):89–97.
 6. Vилlecco AS, de Aloysio D, Pilati G, Mauloni M, Roncuzzi A, Bottiglioni F, Pisi E. Non-invasive 24-hr monitoring of high blood pressure in climacteric outpatients. *Maturitas*. 1987;9(3):267–74.
 7. Zouhal H, Jacob C, Delamarche P, Gratas-Delamarche A. Catecholamines and the effects of exercise, training and gender. *Sports Med*. 2008;38(5):401–23.
 8. Owens JF, Stoney CM, Matthews KA. Menopausal status influences ambulatory blood pressure levels and blood pressure changes during mental stress. *Circulation*. 1993;88(6):2794–802.
 9. Floras JS. Epinephrine and the genesis of hypertension. *Hypertension*. 1992;19(1):1–18.
 10. Guzzetti S, Piccaluga E, Casati R, Cerutti S, Lombardi F, Pagani M, Malliani A. Sympathetic predominance in essential hypertension: a study employing spectral analysis of heart rate variability. *J Hypertens*. 1988;6(9):711–17.
 11. Zaydun G, Tomiyama H, Hashimoto H, Arai T, Koji Y, Yambe M, Motobe K, Hori S, Yamashina A. Menopause is an independent factor augmenting the

- age-related increase in arterial stiffness in the early postmenopausal phase. *Atherosclerosis*. 2006;184 (1):137–42.
doi:10.1016/j.atherosclerosis.2005.03.043.
12. Han J-Y, Choi D-H, Choi S-W, Kim -B-B, Ki Y-J, Chung J-W, Koh -Y-Y, Chang K-S, Hong S-P. Predictive value of brachial- ankle pulse wave velocity for cardiovascular events. *Am J Med Sci*. 2013;346(2):92–97.
doi:10.1097/MAJ.0b013e318268c05a.
 13. Vlachopoulos C, Aznaouridis K, Terentes-Printzios D, Ioakeimidis N, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with brachial-ankle elasticity index: a systematic review and meta-analysis. *Hypertension*. 2012;60 (2):556–62. doi:10.1161/HYPERTENSIONAHA.112.194779.
 14. Fahs CA, Heffernan KS, Ranadive S, Jae SY, Fernhall B. Muscular strength is inversely associated with aortic stiffness in young men. *Med Sci Sports Exerc*. 2010;42(9):1619–24. doi:10.1249/ MSS.0b013e3181d8d834.
 15. Sanada K, Miyachi M, Tanimoto M, Yamamoto K, Murakami H, Okumura S, Gando Y, Suzuki K, Tabata I, Higuchi M. A cross-sectional study of sarcopenia in Japanese men and women: reference values and association with cardiovascular risk factors. *Eur J Appl Physiol*. 2010;110(1):57–65.
doi:10.1007/s00421-010-1473-z.
 16. Kohara K, Ochi M, Tabara Y, Nagai T, Igase M, Miki T. Arterial stiffness in sarcopenic visceral obesity in the elderly: J-SHIP study. *Int J Cardiol*. 2012;158(1):146–48. doi:10.1016/j.ijcard.2012.04.033.
 17. Ochi M, Kohara K, Tabara Y, Kido T, Uetani E, Ochi N, Igase M, Miki T. Arterial stiffness is associated with low thigh muscle mass in middle-aged to elderly men. *Atherosclerosis*. 2010;212(1):327–32.
doi:10.1016/j.atherosclerosis.2010.05.026.
 18. Maslow AL, Sui X, Colabianchi N, Hussey J, Blair SN. Muscular strength and incident hypertension in normotensive and prehypertensive men. *Med Sci Sports Exerc*. 2010;42(2):288–95. doi:10.1249/MSS.0b013e3181b2f0a4.
 19. Silverman HG, Mazzeo RS. Hormonal responses to maximal and submaximal exercise in trained and untrained men of various ages. *J Gerontol A Biol Sci*

- Med Sci. 1996;51(1):B30–7.
20. Hagberg JM, Seals DR, Yerg JE, Gavin J, Gingerich R, Premachandra B, Holloszy JO. Metabolic responses to exercise in young and older athletes and sedentary men. *J Appl Physiol.* (1985) 1988;65(2):900–08. doi:10.1152/jappl.1988.65.2.900.
 21. Wong A, Figueroa A, Son W-M, Chernykh O, Park S-Y.. The effects of stair climbing on arterial stiffness, blood pressure, and leg strength in postmenopausal women with stage 2 hypertension. *Menopause.* 2018;25(7):731–37. doi:10.1097/ GME.0000000000001072.
 22. Son W-M, Sung K-D, Cho J-M, Park S-Y. Combined exercise reduces arterial stiffness, blood pressure, and blood markers for cardiovascular risk in postmenopausal women with hypertension. *Menopause.* 2017;24(3):262–68. doi:10.1097/GME.0000000000000765.
 23. Figueroa A, Park SY, Seo DY, Sanchez-Gonzalez MA, Baek YH. Combined resistance and endurance exercise training improves arterial stiffness, blood pressure, and muscle strength in postmenopausal women. *Menopause.* 2011;18(9):980–84. doi:10.1097/ gme.0b013e3182135442.
 24. Tanaka H, DeSouza CA, Seals DR. Absence of age-related increase in central arterial stiffness in physically active women. *Arterioscler Thromb Vasc Biol.* 1998;18(1):127–32.
 25. Pons van Dijk G, Lenssen AF, Leffers P, Kingma H, Lodder J.. Taekwondo training improves balance in volunteers over 40. *Front Aging Neurosci.* 2013;5:10.
 26. Seo M-W, Jung H-C, Song J-K, Kim H-B. Effect of 8 weeks of pre- season training on body composition, physical fitness, anaerobic capacity, and isokinetic muscle strength in male and female collegiate taekwondo athletes. *J Exerc Rehabil.* 2015;11(2):101–07. doi:10.12965/jer.150196.
 27. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, Nieman DC, Swain DP. American college of sports medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently

- healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334–59. doi:10.1249/MSS.0b013e318213febf.
28. Ziegler MG, Lake CR, Kopin IJ. Plasma noradrenaline increases with age. *Nature.* 1976;261(5558):333–35.
29. Morrow LA, Linares OA, Hill TJ, Sanfield JA, Supiano MA, Rosen SG, Halter JB. Age differences in the plasma clearance mechanisms for epinephrine and norepinephrine in humans. *J Clin Endocrinol Metab.* 1987;65(3):508–11. doi:10.1210/jcem-65-3-508.
30. Hoeldtke RD, Cilmi KM. Effects of aging on catecholamine metabolism. *J Clin Endocrinol Metab.* 1985;60(3):479–84. doi:10.1210/jcem-60-3-479.
31. Young JB, Rowe JW, Pallotta JA, Sparrow D, Landsberg L. Enhanced plasma norepinephrine response to upright posture and oral glucose administration in elderly human subjects. *Metabolism.* 1980;29(6):532–39.
32. Lakatta EG. Deficient neuroendocrine regulation of the cardiovascular system with advancing age in healthy humans. *Circulation.* 1993;87(2):631–36.
33. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL, Jones DW, Materson BJ, Oparil S, Wright JT, et al. The seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure: the JNC 7 report. *JAMA.* 2003;289(19):2560–72. doi:10.1001/jama.289.19.2560.
34. Ohta M, Hirao N, Mori Y, Takigami C, Eguchi M, Tanaka H, Ikeda M, Yamato H. Effects of bench step exercise on arterial stiffness in post-menopausal women: contribution of IGF-1 bioactivity and nitric oxide production. *Growth Horm IGF Res.* 2012;22(1):36–41. doi:10.1016/j.ghir.2011.12.004.
35. Jurca R, Church TS, Morss GM, Jordan AN, Earnest CP. Eight weeks of moderate-intensity exercise training increases heart rate variability in sedentary postmenopausal women. *Am Heart J.* 2004;147(5):e21. doi:10.1016/j.ahj.2003.10.024.