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The Impact of Sedentary Behavior on Arterial Stiffness in Physically Active College Students

A Senior Honors Thesis

Submitted in Partial Fulfillment of the Requirements for Graduation in the Honors College

By
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Abstract:

Previous research has linked sedentary behavior (SB) to increased arterial stiffness (AS) and subsequent cardiovascular disease (CVD). Yet few studies have examined the AS of healthy individuals who are currently engaging in daily moderate to vigorous physical activity (MVPA). *Purpose*: To examine the impact of SB on AS in physically active college students. *Methods*: 43 college students volunteered to participate in this study, 35 participants completed the study, and of these participants, 27 met the recommended exercise guidelines of 30 minutes of moderate to vigorous physical activity (MVPA) per day (age: 20.5 + 1.64 years; height: 167.52 + 9.41 cm; weight: 72.23 + 17.18 kg; Body Mass Index (BMI): 25.81 + 6.32 kg/m^2). On the first visit, participants completed demographic questionnaires and received an accelerometer to wear for at least ten days. They then returned to the lab within two weeks and completed the International Physical Activity Questionnaire- short form (IPAQ-S) and underwent anthropometric measurements. Lastly, AS was measured non-invasively via pulse wave velocity (PWV). Based on accelerometry data, participants were separated into two groups for data analyses: active couch potatoes (ACP) (> 600 min/d sedentary) and active (ACT)(< 600 min/d sedentary). *Results:* Average PWV among our participants was 6.26 + 2.16 m/s. Participants spent 602.45 + 122.94 minutes/day sedentary, and 59.47 + 21.05 minutes/day engaging in MVPA. Pearson correlation showed a statistically significant relationship between PWV and SB in ACP males and ACT males. Males in the ACP group had a significantly higher PWV than ACT males. *Conclusion*: Our study found a significant positive relationship between SB and PWV in males who achieved the recommended amount of MVPA. Previous literature has indicated a significant positive correlation between SB and AS, yet has not examined the effects of SB on AS in those acquiring daily MVPA. Future research should work to define excessive SB in order to

differentiate between active couch potatoes and active individuals.

Introduction:

Cardiovascular fitness is a key component of health. Arterial stiffness (AS) is a high quality indicator of cardiovascular health and can be measured non-invasively via pulse wave velocity (PWV). PWV measures the length of time that the arterial pulse propagates through the circulatory system. More compliant arteries attenuate the pressure on the blood vessels, reducing the speed at which the pressure wave returns to the aorta. Subsequently, pressure waves return during diastole, and assist in the perfusion of blood to the coronary arteries. Conversely, when an artery stiffens, the speed of the pulse wave returning to the heart increases, resulting in the return of blood during systole, increasing pressure at the heart during contraction. The carotid-femoral PWV is the 'gold-standard' measurement of AS, and has been used to predict and diagnose pathophysiologic conditions including CV events, hypertensions, diabetes, renal failure, and coronary heart disease (16).

Cardiovascular disease (CVD) is one of the leading causes of death and disability in the United States. One of the earliest signs of CVD is atherosclerosis, the process of deposition of plaque on the walls of arteries, causing stiffening and narrowing of artery walls, and reducing blood flow. As a result of altered blood flow, atherosclerosis leads to myocardial infarctions, strokes, and peripheral artery disease. Subsequently, the walls of arteries stiffen and are unable to completely dilate to allow for greater blood flow (17). Therefore, measurement of AS is an important predictor of CVD and many studies have examined the contributors to AS and subsequent CVD (19). With aging, for example, PWV increases from younger to middle- aged individuals, which subsequently increases the likelihood of a cardiac event. Age related AS is quite common and may be due to the reduction of elastin in the arteries and a buildup of plaque on the walls of the vessels (8). Physical activity (PA) may play a role in slowing down this process, while increased SB may increase AS due to a reduction in elastic properties (8). Those who meet the PA recommendations provided by the American College of Sports Medicine (ACSM) of 30 minutes per day, at least five days per week, are likely to have more compliant arteries later in life (1).

Arterial stiffness represents the relationship between the change in pressure and the change in volume in arteries. Blood is pumped from the heart to the organs through arteries. The artery wall has a large amount of elastic fibers, enabling the arteries to expand during systole. During diastole, blood is pushed through the arteries as a result of the elastic recoil. This mechanism ensures that blood continues to flow in one direction. Peripheral arteries have increased collagen fibers, resulting in the arteries being less compliant (24). The decreased compliance also occurs with aging, obesity, smoking, disease, and SB.

Hypertension is a CVD classified as high blood pressure. Blood pressure is an important factor that alters the compliance of arteries. As blood pressure rises, arteries increase in size, and use more collagen fibers, resulting in a decrease in elasticity. Elastic-collagen compositions of arterial walls are a chronic component to the stiffness of arteries. Changes in the elastic-collagen compositions take many years to occur (22). As diastolic blood pressure increases, there is an increase in pulse wave velocity (PWV) as well. For every 7 mmHg rise in diastolic blood pressure, there is an associated average of 0.21 m/s increase in PWV (4). A lack of vasodilation combined with increased blood flow velocity contributes to stiffening of arteries (19).

Along with hypertension, AS is also a known risk factor for and early sign of CVD. Previous studies have examined the contribution of other risk factors such as smoking, obesity, diabetes, sedentary lifestyle, dyslipidemia, family history, age, and hypertension (1) to AS and

CVD. Crichton et al. (4) examined the effects of health behaviors and factors on cardiovascular health. Health behaviors included smoking, body mass index, PA, and diet. Health factors included total cholesterol, blood pressure, and fasting plasma glucose. They hypothesized that those with more ideal cardiovascular health factors and health behaviors would have lower PWV and pulse pressure, indicating lower AS. Participants completed questionnaires about PA, nutrition, and self-rating of health. Measurements of cholesterol, plasma glucose, triglycerides, weight, height, blood pressure, and PWV were also assessed. A Recommended Food Score and non-Recommended food score were calculated using a questionnaire that asked participants how frequently they consumed each food. This method was used to obtain a more detailed report of dietary intake. Using the AHA definitions of ideal levels of cardiovascular health components each participant was given a Cardiovascular Health Score (CHS) ranging from 0 to 8, where 0 indicated no cardiovascular health components at ideal levels, and 8 indicated all cardiovascular components at ideal levels. Using the CHS, participants were separated into three groups: low cardiovascular health (CHS of 0-2), medium (CHS of 3-4), and high cardiovascular health (CHS of 5-8). Results of this study indicated that systolic blood pressure and glucose are more closely related to PWV. Total cholesterol is next closely related to PWV, and BMI has the lowest relation. Self-reported health showed to be the least accurate method in predicting PWV. The main finding of this study was the PWV and pulse pressure values were significantly lower for the high CHS group than the lowest CHS group. However, no differences were seen for the medium and high CHS groups. This study concluded that those with five or more ideal cardiovascular health components had significantly lower PWV and pulse pressure than those with two or less ideal cardiovascular health components. The findings are consistent with the hypothesis that a higher CHS is associated with a lower PWV. There was a significant decrease between the medium and low groups. Having more cardiovascular health components at ideal levels is related to lower levels of PWV and lower AS. Improvements in health behaviors and health factors may reach a plateau, however, small changes in diet, physical activity, and weight loss may directly improve the compliance of arteries (4).

Obesity, defined as body mass index (BMI) greater than or equal to 30 kg/m^2 is also a significant contributor to AS and CVD (1). Safar et al. (19) investigated the relationship between BMI and waist circumference and PWV in a group of participants with and without obesity. All participants, however, were diagnosed with essential hypertension. For the obese participants, PWV measurements were significantly higher compared to the non-obese participants. Furthermore, when the results were assessed, waist circumference was found to be more closely related to AS than BMI (19).

The location of body fat may also play a role in extent of AS. Visceral adiposity, for example, is more dangerous to the organs than subcutaneous fat. An increase in lipolytic activity and a higher inflammatory profile of visceral adipocytes results in the release of free fatty acids and inflammatory proteins into the hepatic portal vein, contributing to insulin resistance (12). Since visceral obesity is more closely associated with AS than BMI, measurement of the compliance of arteries have been studied in individuals with diabetes and metabolic syndrome (13). It has been determined that reduced elasticity is present in central and peripheral arteries in these individuals. However, in those with hypertension, central arteries are less compliant, while peripheral arteries have normal values. This physiological process may result in the hardening of arteries as a result of plaque buildup. Additionally, increases in circulating cytokines, such as leptin, may play a role in the correlation between increased visceral fat and increased AS. High levels of leptin are found in individuals with obesity, and are correlated with the stiffening of arteries (2). Leptin increases sympathetic nervous system activity, resulting in increased blood pressure. (20).

Exercise is a proven method for decreasing CVD risk factors. In particular, exercise decreases AS by lowering body fat, blood pressure, cholesterol, and other risk factors. However, the exact duration and intensity of exercise at which individuals will benefit has not yet been identified. Research by Sung et al. (22) investigated the effects of short-duration exercise on AS in patients with coronary artery disease. The researchers used a treadmill test and brachial-ankle pulse wave velocity (baPWV) measurement on 50 patients with coronary artery disease (CAD) and 50 age-matched controls. Brachial-ankle pulse wave velocity is another indicator of AS and shows large artery stiffness and endothelium-dependent peripheral vasodilation (22). Impairment of endothelium-dependent peripheral vasodilation limits the effect on nutritive skeletal muscle blood flow, and therefore may contribute to exercise intolerance in patients with heart failure (14). Prior to a graded exercise test, AS was measured using an automatic system that recorded baPWV, brachial blood pressure, and ankle blood pressure on both sides of the body. Within ten minutes from the time of completion, baPWV was measured again. Differences between the CAD and control groups, as well as pre- to post-exercise differences in each group were assessed and compared. The results indicated that at baseline, baPWV values for the CAD group was higher than the control group. Following exercise, baPWV values significantly decreased for both the CAD group and the control group. The decrease in baPWV from pre- to post-exercise was significantly larger for the CAD group since the baseline value was higher. The control group showed significantly lower values for systolic blood pressure and mean arterial pressure after exercise than at baseline, and no significant change in diastolic blood pressure. The CAD group also demonstrated lower values for mean arterial pressure after exercise when compared to baseline values, but not a significant difference in values of systolic and diastolic blood pressures. When adjusting for differences in age, body mass index, systolic blood pressure, mean arterial pressure, mean arterial pressure reduction, and baseline baPWV, the CAD group had a larger decrease in baPWV ten-minutes post-exercise than the control group. Although exercise time was lower for the CAD group, they still had a larger decrease in baPWV, suggesting that duration does not significantly affect changes in baPWV (22). Although this study concluded that short-duration exercise results in an immediate decrease in baPWV, even in patients with existing CAD, more research must be done to determine the effects of repeated short-duration aerobic exercise on AS.

The effects of exercise on AS are likely due to changes of smooth muscle cells in arterial walls. The change in tone of smooth muscle cells is related to the production of nitric oxide (NO), a gas that is released by endothelial cells that subsequently aid in vasodilation by relaxing the smooth muscle surrounding the blood vessels. The stress caused by exercise promotes the release and the production of NO. In patients with CAD, NO production is reduced, resulting in endothelial dysfunction and contributing to stiffer vessels. Exercise however, promotes NO production and subsequently decreases AS (22).

A common co-morbidity associated with obesity is insulin resistance. Insulin is a hormone that regulates how the body uses and stores glucose and fat. The body uses insulin to uptake glucose for energy. In individuals with type II diabetes, the ability of insulin to decrease pressure in the aorta is reduced because of the decreased production of insulin, or increased resistance, possibly leading to stiffening of arteries early in life. It is likely that those with insulin resistance will develop hypertension and increased complications (12). Factors such as the increase in blood flow velocity while the diameter of the artery remains unchanged, or an increase in sympathetic neural activation may explain increased AS in individuals with more visceral fat. However, when an individual loses weight, specifically visceral fat, the increased stiffness of the arteries, as well as heart rate, can be reversed. Based on findings by Safar et al, PWV and mortality increases in those with diabetes and glucose intolerance when compared to control subjects (19). Therefore, PWV is a strong predictor of cardiovascular morbidity, mortality, and all-cause mortality, especially for those with diabetes or metabolic syndrome. Due to the findings that visceral fat is more closely associated with AS than BMI, waist circumference is a good indicator of cardiovascular health. Knowing that increased abdominal fat causes increased aortic stiffness, individuals should be very cautious of location of body fat, rather than overall amount of body fat. This knowledge can help improve cardiovascular health.

The process of arteries stiffening occurs even faster in patients with diabetes. The cause of accelerated stiffening of arteries in diabetic patients may be due to the reaction that occurs in the walls of arteries between blood glucose and extracellular matrix proteins. This leads to formation of more collagen crosslinks, decreasing the compliance of arteries. Aerobic exercise may stretch and break the crosslinks between the collagen fibers, resulting in a decrease of AS. Madden et al. examined the effects of aerobic exercise on AS in adults at high risk for CVD. They hypothesized that aerobic exercise would reduce AS in these individuals despite the many factors contributing to AS. 36 older adults (18 males and 18 females) participated in the study, all of which were living with type II diabetes, hypertension, and hyperlipidemia. Prior to the study, the subjects were sedentary for at least six months, then randomly assigned to either the aerobic group or the non-aerobic group. Both groups completed a pre- and post- intervention evaluation assessing anthropometric measurements. The aerobic group completed moderate to vigorous intensity exercise (60-75% of heart rate reserve) on a treadmill or cycle ergometer three times per week for three months. Sessions were sixty minutes, consisting of a ten-minute warm up, 40 minutes of aerobic training, and a ten-minute cool down. The non-aerobic group completed core training using an exercise ball, and strength training using dumbbells three times per week for three months. Before, during, and after exercise, blood pressure, heart rate, and blood glucose were measured and recorded (6). When measuring PWV, participants rested for 30 minutes prior to the use of two pressure transducers placed on the carotid and femoral arteries, as well as the radial and carotid arteries. The femoral PWV has been shown to have a direct link to CVD, and is therefore the best indicator for CVD risk (13). Heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure were also measured and recorded, as well as body weight, BMI, waist and circumferences, waist to hip ratio, and maximal oxygen consumption.

Madden et al. (13) found that before the training intervention there was no significant differences in PWV between the groups. After training, the aerobic group had decreased values in radial and femoral PWV, while the non-aerobic group had an increase in the radial and femoral PWV values (13). The main finding of this study was that only three months of aerobic training in an extremely high risk population resulted in decreased PWV independently of changes to cholesterol, blood pressure, weight, and resting heart rate. Therefore, exercise may have a direct impact on AS, and increased compliance of arteries could possibly occur without improvement of aerobic fitness. Exercise may decrease AS independently of other risk factors by impacting endothelial function, inflammation, and sympathetic activity.

Sugawara et al. (21) further studied the impact of PA duration and intensity on carotid arterial stiffness (21). They examined 103 healthy, non-smoking, postmenopausal women. They hypothesized that moderate and vigorous PA would result in lower AS in postmenopausal women due to the release of sex hormones. The duration and intensity of PA was evaluated via accelerometry for 14 days after which they were randomly assigned into two groups for a 12-week training program consisting of cycling three to five times per week. One group worked at 4 METs and the other group worked at 7 METs. Non-invasive methods of measurement of PWV taken after the 12-week training program included an oscillometric device, ultrasound imaging, and a linear transducer. Results indicated that PWV was significantly related to duration of moderate and vigorous exercise, but not low intensity exercise. The accelerometer data determined that older subjects spent less time participating in low intensity PA, and duration of moderate and vigorous intensity exercise was not correlated with age. Measurements were extremely similar at baseline, except heart rate was lower in the vigorous intensity group. Body mass index and body weight decreased for the vigorous group, but not the moderate group. Heart rate, brachial blood pressure, carotid blood pressure and the diameter of the carotid lumen did not change in the moderate or vigorous groups. AS significantly decreased in both the moderate and vigorous groups. Based on these findings, it can be concluded that the effects of moderate intensity exercise on AS is not different from the effects of vigorous intensity exercise (21). These findings can be implemented into training methods since it is easier to participate in moderate intensity PA than vigorous intensity. Knowing that both intensities have the same effects on AS, more individuals are likely to participate in moderate intensity PA rather than vigorous intensity or no exercise at all.

The decreases in AS seen in moderate and vigorous intensity PA are likely due to the enhanced endothelium-dependent vasodilation. Regular aerobic exercise stops endothelium vasoconstriction by blocking hormones (21). These changes may be linked with a decrease in vascular smooth muscle tone, which results in decreased AS. The findings of Sugawara et al.

indicate that AS is related to duration of exercise at moderate and vigorous intensity PA, and that both intensities elicit similar changes in AS. Shear stress caused by vigorous exercise produces NO, which relaxes endothelial cells, causing vasodilation. NO is released from endothelial cells then diffuses into smooth muscle cells lining blood vessels. Once NO is inside of the smooth muscle cells NO then binds to an enzyme. When the enzymes become activated, new proteins are formed, including myosin. Myosin is the protein that causes smooth muscle to contract. Next, myosin becomes phosphorylated, resulting in dilation of the blood vessel (3).

While exercise has been a proven method of preventing, and reversing AS, behaviors can negatively impact cardiovascular health. Sedentary behavior (SB) is defined as activities less than or equal to 1.5 METs (1). Individuals are defined as sedentary if they do not participate in aerobic exercise for 30 to 60 minutes per day on at least three to five days of the week for at least six months. Sitting has been linked with obesity, type II diabetes, metabolic syndrome, CVD and morality (1). Therefore, it is likely that SB also impacts AS. Additionally, intensity of PA has also been shown to play a role in cardiovascular health. Light intensity exercise and MVPA affect the body in different ways, and these differences have been studied.

For example, Gando et al. (6) examined the relationship between light PA and AS. They hypothesized that greater time spent in light PA would be associated with lower AS. Participants were grouped depending on time spent per day in light PA and further split into three age groups: less than 40 years old, 40 to 59 years old, and 60 or older. To track PA and sedentary time the subjects wore accelerometers for at least 14 days (6). A cycle exercise test was used to determine maximal oxygen consumption to then split the subjects into two groups: fit and unfit. They then examined the difference that light PA had on AS in fit and unfit adults. The results concluded that in both young and old individuals, percent of body fat was higher in the low-light PA group, while blood pressure, mean arterial pressure, and plasma glucose was higher in the low-light PA group in older adults. In the older group, PWV was higher in the low-light PA subjects than the high-light. In the middle and older group, PWV was higher than the younger group for low-light and high-light PA groups. Time spent in light PA was longer, and the time spent in inactivity was shorter in the middle and older aged groups compared to the younger group. Time spent in vigorous PA was higher in the younger group (6).

Overall, Gando et al. (6) determined that PWV was not significantly related to the amount of time spent in light PA or inactivity. The young group showed no relationship between moderate to vigorous PA (MVPA) and PWV. Finally, in the older group it was determined that PWV was significantly related to the amount of time spent in light and moderate PA and amount of time spent sedentary per day. However, no significant differences were seen on PWV due to vigorous PA. In the older group, differences were significant between the unfit and fit individuals. There was no relationship between PWV and time spent in light physical activity for the fit individuals, but the unfit individuals had a significant correlation between PWV and MAP with daily time spent in light physical activity (6).

The older group had higher AS in the low-light PA group than the high-light group, and a negative relationship was observed between time spent in light PA and AS. The less sedentary time that individuals participated in, the lower the PWV. These results suggest that the more time spent sedentary, the higher the PWV, especially in unfit older adults. These finding can be implemented by increasing duration of light PA, which is easier to accomplish for older adults. For the older, unfit population, moderate and vigorous exercise training is not necessary to see improvements in AS. Replacing sedentary time with light PA may reduce AS in older adults. The longer time spent in light intensity PA, more benefits to blood pressure, heart rate, and plasma glucose will be observed. Additionally, light PA improves the availability of NO, vascular smooth muscle tone, and collagen cross-links (6).

While the ACSM and the AHA states that meeting the recommended amount of moderate to vigorous intensity aerobic activities, as well as light intensity activities of daily living results in decreased sitting time, there are no guidelines regarding sitting specifically (15). Many studies investigate the effects of moderate to vigorous exercise on cardiovascular health, but less research has been done regarding SB. Sedentary behavior, such as sitting, watching television, using the computer, and other activities requiring less than 1.5 METs leads to decreased metabolic health. Unfortunately, with increases in the use of technology and less demand for physical labor, many Americans spend the majority of their day inactive. The negative impact on health is even evident in those who achieve regular PA, but still accumulate excessive sedentary time. The Active Couch Potato, a term used to describe these individuals, are still at risk for obesity, type II diabetes, cardiovascular disease, and certain types of cancers (15). The correlation between increased sitting time and decreased cardiovascular health may be a result of the loss of contractile stimulation, the reduction of lipoprotein lipase in the skeletal muscles, and reduction in the uptake of glucose. Lipoprotein lipase is an enzyme that is needed for the uptake of triglycerides, as well as the production of high- density lipoprotein cholesterol (15). However, this mechanism may be reversed through PA and even while standing (15). Therefore, increasing standing time may improve cardiovascular health.

Healy et al. (9) further investigated the relationships between total sedentary time and obesity, glucose metabolism, and metabolic syndrome. They examined the way that sedentary time is accumulated and the association of breaks in sedentary time with CVD risk. Using an accelerometer for seven consecutive days, sedentary time was measured during waking hours.

Breaks were defined as interruptions in sedentary time. Results showed that independent of the amount of sedentary time of physical activity that an individual participates in, breaks in sedentary time benefited metabolic markers (9). The finding can be implemented by creating new health recommendations, including guidelines for breaking up sedentary time. With the knowledge that metabolic markers are a strong indicator of arterial stiffness, breaking up sedentary time will decrease PWV.

Many studies have been done to examine the effects that exercise has on AS measured through PWV. Subjects of all ages have been studied, however, mostly older adults are participants of studies about AS. This is likely due to the fact that most changes are seen in older adults due to the increase in AS with age. In younger individuals who have not yet developed AS it is more difficult to measure changes due to exercise and SB. It has been determined through multiple studies that meeting the recommended guidelines for exercise will increase compliance of arteries. Slowing down the process of AS through exercise and a healthy diet are extremely important in preventing CVD. Pulse wave velocity is the best measurement of AS and indicator of overall cardiovascular health. With the knowledge of the benefits of reaching the recommended exercise guidelines to increase cardiovascular health, it is still unknown if participation in purposeful exercise is better than being physically active throughout the day. More research must be done to determine if those who do not exercise for at least 30 minutes per day, but are active at a lower intensity for the majority of the day will have similar benefits to cardiovascular health as those who exercise for 30 minutes, but are sedentary for the remainder of the day.

<u>Methods:</u>

College students at The College at Brockport, ages 18 to 30 years, volunteered to participate in this cross-sectional analysis (N=43; age: 20.5 + 1.64 years; height: 167.52 + 9.41 cm; weight: 72.23 + 17.18 kg; Body Mass Index (BMI): 25.81 + 6.32 kg/m^2). Exclusion criteria included cardiovascular, metabolic, pulmonary, or renal disease, musculoskeletal injury, and pregnancy. Of the 43 participants, 36 participants completed the study.

Procedure:

This study was completed in two visits. On visit 1, participants came to the research lab where they were familiarized with the procedure of the study. Participants read and signed an informed consent, completed a Health History Questionnaire (HHQ) and a demographic questionnaire. Next, the height and weight of each participant was measured and recorded. Height was measured using a stadiometer (Seca, Germany) and weight was measured using a load cell scale (Seca, Germany). An accelerometer (Actigraph, Pensacola, FL) was distributed to the participant at the end of the first visit. The participants were instructed to wear the accelerometer around their waist at the right hip for 10 days. The accelerometer was worn at all times except during activity involving physical contact, and activities that involved the accelerometer getting wet. Participants were able to wear the accelerometer to sleep, but it was not necessary to the data being collected.

At least 10 days later, and no more than 14 days, participants returned to the research lab for visit 2. Anthropometric measurements were taken including height, weight, waist and hip circumferences, and body fat percentage. Height and weight were used to calculate body mass index (BMI) and waist and hip circumferences were used to calculate waist to hip ratio. Waist and hip circumferences were measured using a Gullick tape measure. Measurements were taken twice for accuracy. Body fat percentage was measured using bioelectrical impedance analysis (BIA) (Bodystat, British Isles). The procedure for using the BIA began with the participant lying in the supine position. Two electrodes were placed on the right ankle and two electrodes were placed on the right wrist. The participant was instructed to remain still, while a safe battery generated signal was transmitted through the body to measure impedance at a frequency of 50 kHz. This source of measurement assumes limb length, hydration status, and body fat distribution. After measuring body fat percentage, arterial stiffness was measured. The Sphygmocor Xcel non-invasive system was used to measure the central arterial pressure waveform analysis. The carotid-femoral pulse wave velocity (PWV) was measured using this system. The procedure for measuring PWV began with the participant lying in the supine position with a blood pressure cuff around the right upper thigh to measure the pressure at the femoral artery. Once the cuff was properly placed on the participant, three distances were measured in millimeters using a Gullick tape measure, then entered into the computer. These measurements included the carotid artery to the sternal notch, the sternal notch to the top of the femoral cuff, and the femoral artery to the top of the femoral cuff. Next, the carotid artery on the right side of the neck was found. The cuff was inflated while an applanation tonometer was pressed into the carotid artery. This was used to measure the carotid artery waveform. The software used the distance that the blood traveled and the time of blood flow between the carotid and femoral arteries to determine velocity.

After PWV was measured, the participant completed a Sugar Sweetened Beverage (SSB) and a nutrition consumption interview. The SSB interview asked the participants to record the average daily consumption of beverages with added sugar, including coffee with cream and/or sugar, juice, sports drinks, soft drinks, flavored milks, alcoholic beverages, and any other drinks containing added sugar. The nutrition consumption interview asked the participant to record the amount of different food groups consumed during the ten days. Next, the participant was instructed to complete the self-reported physical activity questionnaire, the International Physical Activity Questionnaire-Short form (IPAQ-S). This form asked the participants to record how many minutes they spent per day participating in moderate and vigorous physical activity, as well as how many minutes they spent walking and sitting. The data received from the self-reported questionnaire was used as a back-up measure of physical activity for the accelerometers. After the completion of the forms, the accelerometer was collected from the participants.

Data Analyses:

Using the Actilife software, accelerometer data was analyzed. Data from the accelerometer included minutes spent sedentary, minutes spent participating in moderate to vigorous physical activity, and the number of sedentary bouts. Data was analyzed using SPSS Version 24 (IBM, Chicago, IL).

Data are presented as mean ± standard deviation. A significance level was set at $p < 0.05$. A one-way ANOVA test was run to assess the differences in males and females in PWV between the sedentary (Sed) group, active couch potato (ACP) group, and the active (ACT) group. A Tukey Post Hoc test was run to determine where the difference was between groups.

Results:

43 college students 18-30 years old volunteered to participate in the study. 36 participants completed the study. 28 participants met the recommended guidelines of physical activity of 30 minutes of moderate to vigorous physical activity (MVPA) (1). 8 participants did not meet those guidelines and were grouped as sedentary. The 28 participants who met the PA guidelines were split into two groups: active couch potato (ACP) and active (ACT). Those who were in the ACP group met the recommended guidelines of PA and also accumulated ≥ 600 minutes per day of sedentary behavior, while those who were in the ACT group met the guidelines of PA and

accumulated < 600 minutes per day of sedentary behavior. Baseline characteristics of subjects are listed in Table 1.

Table 1. Baseline Characteristics

	Sed (n=8)		ACP (n=10)		ACT (n=18)	
Gender	**Male (n=5)**	**Female (n=3)**	**Male (n=4)**	**Female (n=6)**	**Male (n=8)**	**Female (n=10)**
Age (yrs)	21.6±1.8	19.33±0.58	22.25±2.63	19.5±1.38	21.25±0.71	19.80±1.14
Height (cm)	179.82±8.0	162.7±9.49	180.18±3.86	158.17±2.84	174.41±6.87	162.56±4.54
Weight (kg)	73.54±11.0	81.37±26.10	85.38±6.45	60.98±8.71	70.65±8.11	74.97±24.64
BMI (kg/m^2)	22.67±1.73	30.27±5.98	26.38±2.55	24.40±3.39	23.34±3.17	28.41±9.44
BF %	10.74±3.88	34.73±8.62	18.45±4.70	23.13±5.96	13.68±5.98	29.06±8.02
WHR	0.78±0.21	0.80±0.088	0.799±0.048	0.73±0.044	0.80±0.29	0.74±0.059
BSBP (mmHg)	139.0 ± 7.2	129.33 ± 14.57	132.25 ± 15.13	121.0 ± 7.70	136.25 ± 8.65	122.6 ± 11.17
BDBP (mmHg)	70.4 ± 15.74	75.33 ±17.01	77.25 ± 7.5	67.5 ± 4.09	75.2 ± 8.36	73.3 ± 6.08

N=sample size; Sed=sedentary; ACP=active couch potato; ACT=active; yrs=years; cm=centimeters; kg=kilograms; BMI=Body Mass Index; kg/m^2=kilograms per meters squared; BF%= Body Fat Percentage; mmHg=millimeters of mercury; WHR=waist to hip ratio; BSBP=brachial systolic blood pressure; BDBP=brachial diastolic blood pressure

AS was measured through PWV and augmentation index corrected to a heart rate of 75 bpm (AIX_{75}) (Table 2).

Table 2. Arterial Stiffness

	Sed (n=8)	ACP (n=10)	ACT (n=18)

Gender	Male (n=5)	Female (n=3)	Male (n=4)	Female (n=6)	Male (n=8)	Female (n=10)
AIX75 (%)	0.80±15.74	24.67±38.73	6.00±16.97	6.33±6.38	3.38±10.43	9.70±13.21
PWV (m/s)	5.98±0.61	5.53±1.07	7.00 ± 0.50	4.73±0.19	5.45 ± 0.83	4.81±0.87
CSBP (mmHg)	116.4 ± 6.35	115.00 ± 21.07	115.25 ± 10.34	103.83 ± 4.26	116.63 ± 6.44	107.40 ± 10.10
CDBP (mmHg)	72.4 ± 7.99	8.00 ± 21.07	78.75 ± 7.63	67.67 ± 4.23	76.5 ± 8.47	74.70 ± 6.29

AIX75=Augmentation index corrected to 75 beats per minute; %=percent; PWV=pulse wave velocity; m/s=meters per second; CSBP=central systolic blood pressure; CDBP=central diastolic blood pressure; mmHg=millimeters of mercury; sed=sedentary; ACP=active couch potato; ACT=active

Physical activity data was tracked using an accelerometer. Time spent per day engaging in sedentary behavior as well as time spent participating in moderate to vigorous physical activity was recorded in minutes. The number of sedentary bouts per day was recorded as well (Table 3).

Table 3. Physical Activity Data

	Sed (n=8)		ACP (n=10)		ACT (n=18)	
Gender	**Male (n=5)**	**Female (n=3)**	**Male (n=4)**	**Female (n=6)**	**Male (n=8)**	**Female (n=10)**
Sedentary Behavior (mins)	1166.48 ± 223.11	516.57 ± 170.32	745.76 ± 57.86	724.85 ± 155.96	509.70 ± 74.31	521.69 ± 62.64
Sedentary Bouts	13.28 ± 11.73	15.09 ± 6.05	23.07 ± 7.01	32.42 ± 31.37	13.0 ± 3.91	31.30 ± 37.91
MVPA (mins)	23.48 ± 6.77	26.79 ± 2.73	57.86 ± 23.92	66.15 ± 24.56	57.49 ± 18.80	52.72 ± 14.72

MVPA=moderate to vigorous physical activity; mins=minutes; sed=sedentary; ACP=active couch potato; ACT=active

An ANOVA test was run to compare PWV between groups. There was a significant difference in PWV among males (p=0.002). A Tukey Post Hoc test revealed the difference to be between ACP (7.0 ± 0.5) and ACT (5.45 ± 0.83), (p=0.038). This indicates that in college age males who meet the physical activity guidelines of 30 minutes per day of MVPA, those who accumulate 600 minutes per day or more of sedentary time have a significantly higher PWV than those who accumulate less than 600 minutes per day of sedentary behavior.

Discussion:

The purpose of this study was to examine the impact of SB on AS in physically active college students. Physical activity data included minutes spent engaging in sedentary behavior, number of sedentary bouts, and minutes spent participating in MVPA. Anthropometric measurements related to physical inactivity included BMI, body fat percentage and WHR. Other anthropometric measurements included age, height, weight, and brachial blood pressure. PWV, augmentation index, and central blood pressure were assessed to analyze AS. A significant difference was found between active couch potato males and active males such that ACP males had greater AS than ACT males. These findings are consistent with the hypothesis of this study that of those individuals who meet the recommended PA guidelines of 30 minutes per day, but accumulate high amounts of sedentary time for the remainder of the day will have a higher PWV than those who meet the recommended PA guidelines and accumulate low amounts of sedentary time throughout the day.

The findings of this study are consistent with previous research, indicating that individuals who are sedentary for most of their day will have a higher PWV than those who remain active throughout the day. It is known that arteries stiffen with age, and previous studies have proven that PA decreases the buildup of plaque that occurs with aging. While participants within many studies have included older adults and individuals with preexisting CVD, few studies have analyzed the effects of SB on AS in college students ages 18 to 30.

A previous study examined the relationship between sedentary behavior and AS in young adults. Huynh et al. studied 2328 participants ages 26 to 36 years, measuring AS, and recording sitting time and PA via a self-reported questionnaire. Results of this study indicated that sitting time during weekend days was correlated with AS and cardiorespiratory fitness (11). A positive correlation between sitting time and AS indicated that increased sitting time is related to increased AS.

Another study conducted from 1982 to 2013 examined the associations between PA and SB and PWV in Brazilian young adults. Horta et al. (10) studied 1241 participants from birth to 30 years of age. Time spent engaging in daily MVPA and SB were recorded via accelerometry. Results of this study showed that PWV was lower in those who were more physically active and that those achieving higher sedentary time also demonstrated higher PWV. Horta et al. (10) concluded that individuals who engaged in at least 30 minutes per day of MVPA had a significantly lower PWV than those who did not meet the recommended guidelines of PA. Young adults with higher sedentary time also had increased AS (10).

Haapala et al. (7) investigated a similar relationship in pre-pubertal children. Sedentary time, light PA, moderate PA, and vigorous PA were assessed using an accelerometer and a heart rate monitor. Results of this study indicated that more time spent in moderate and vigorous PA, as well as total time spent engaging in PA were associated with more compliant arteries (7). Therefore, increased sedentary time leads to greater AS.

While many studies have found that meeting the PA guidelines of 30 minutes per day is related to a lower AS than those who are sedentary, Healy et al. determined that increased breaks in sedentary time benefit metabolic risk factors, such as waist circumference, body mass index, triglycerides, and plasma glucose. The purpose of this study was to examine the association of breaks in sedentary time with biological markers of metabolic risk. Sedentary time was measured using an accelerometer worn for seven consecutive days. Interruptions to sedentary time were recorded as a sedentary break. Results of this study indicated that independent of total sedentary time and total minutes of MVPA, increased breaks in sedentary time reduce metabolic risk factors. This evidence proves the importance of breaking up sitting time throughout the day (9). Although AS was not assessed there was a significant benefit to other metabolic risk factors. Thus, we can predict that AS would also decrease due to breaks in prolonged SB. These findings are consistent with the findings of the current study. Individuals who are active couch potatoes will have higher metabolic and CVD risk factors than those who have more sedentary bouts.

While in the current study there was a significant difference between males, there were many limitations to this study that likely affected the results. Without these limitations, future research may see a greater statistically significant difference in PWV between all groups. Limitations included the small sample size. Of 43 participants, only 36 participants completed the study due to error collecting data or the development of disease during the study. Additionally, there was lack of diversity within the population being studied. Most participants were Caucasian and many participants were students in the Exercise Science major, making it very likely that these students are more physically active than the average college student. More participants from outside the major must be represented to have more accurate results.

Conclusion:

Many studies have been conducted to examine the effects that exercise has on AS measured through PWV. Subjects of all ages have been examined, however, many studies focus on older adults or individuals with signs or symptoms of CVD or metabolic disease. This is likely due to the fact that most changes to AS are seen with aging and/or the presence of disease.

In younger individuals who have not yet developed atherosclerosis, it is more difficult to measure changes due to exercise and sedentary behavior. It has been determined through previous studies that meeting the recommended guidelines for exercise provided by the American College of Sports Medicine (ACSM) of 30 minutes per day on preferably all days of the week will increase compliance of arteries. Slowing down the process of arteries stiffening through exercise and a healthy diet are extremely important in preventing CVD. While the current study indicated a significant difference between PWV in males who are ACP compared to males who are ACT, more research would continue to indicate if those who participate in high sedentary time outside of meeting the guidelines of PA would have a higher PWV than those who meet the guidelines of PA and engage in low amount of sedentary time throughout the day.

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