Article • Effect of Aerobic Exercise of Three Different Intensities on Intraocular Pressure

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ABSTRACT

Background: Previous studies have demonstrated that aerobic exercise is accompanied by an acute reduction in intraocular pressure; however, much of this work suffers from methodological flaws and/or poor description of experimental parameters. The purpose of this study was to determine the acute effects of aerobic exercise of varying intensity on intraocular pressure.

Methods: Twenty-five volunteer participants with normal intraocular pressure (17.17 ± 3.85 mmHg) completed the study. Each participant completed a standardized step test to estimate maximal oxygen uptake, which was used to prescribe individualized treadmill speeds representing three exercise intensities (95%, 65%, and 45% maximal oxygen uptake). In a random and repeated design, participants completed 2.0 km at each intensity. This experimental design isolated power (exercise intensity) as the variable of interest, while holding total work constant for each condition (2.0 km). Baseline intraocular pressure, heart rate, and blood pressure were measured prior to each exercise intensity and again at time 0, 5, 10, and 20 minutes post-exercise.

Results: Aerobic exercise using individualized treadmill speeds equivalent to 95%, 65%, and 45% of estimated maximal oxygen uptake significantly reduced intraocular pressure for all intensities relative to baseline ($p<0.01$). The 95% intensity showed a more significant intraocular pressure reduction than either the 65% and 45% intensities ($p<0.001$).

Conclusion: All exercise intensity levels were associated with an acute reduction of intraocular pressure with higher intensities demonstrating a larger reduction in intraocular pressure. Further study is needed to determine the duration of intraocular pressure reduction following exercise at different intensity levels.

Keywords: exercise, glaucoma, heart rate, intraocular pressure, maximal oxygen uptake

Introduction

Glaucoma represents the second leading cause of blindness worldwide behind cataracts.[1] The most common form of glaucoma, primary open-angle glaucoma, is an incurable progressive optic neuropathy characterized by death of the retinal nerve fiber layer ganglion cells. In primary openangle glaucoma, optic neuropathy is associated with visual field constriction and nerve fiber layer thinning in the presence of open angles on gonioscopy and elevated (>21 mm Hg) intraocular pressure.[2-4] While the exact mechanism of primary open angle glaucoma is not fully understood, it is well established that reduction of intraocular pressure, most commonly through either pharmacological or surgical means, can slow progression of the condition.[5-6] As such, lifestyle modifications that can reduce intraocular pressure represent an exciting therapeutic opportunity in eye care.

Management of many chronic diseases, such as diabetes and hypertension, includes lifestyle modification. One of the most common lifestyle modification recommendations for chronic disease is to increase physical activity.[7] Consistent with these recommendations, clinicians may consider counseling patients with primary open-angle glaucoma to increase physical activity as part of the health management plan; however, clinicians may be unclear as to what type of physical activity recommendations are most beneficial for reducing intraocular pressure, which is problematic because intraocular pressure is influenced differently depending on the type of physical activity. For example, static or isometric activities, such as hand gripping and weightlifting, have been associated with an acute rise in intraocular pressure, which returns to baseline within minutes once the activity is discontinued.[8] In fact, intraocular pressure may increase markedly during weightlifting, particularly when the participant holds their breath during the exercise. Vieira[8] observed an intraocular pressure rise of 5 mm Hg or more in 30% of subjects, with 2 of the 30 subjects experiencing an intraocular pressure increase of 10mmHg or more during a bench press activity when subjects held their breath during the last repetition. Even when utilizing a normal breathing pattern, 21% of subjects demonstrated an intraocular pressure increase of 5 mm Hg or more during the bench press activity. Similarly, several yoga postures, including Adho Mukha Svanasana ("downward facing dog"), Uttanasana ("forward bend pose"), Halasana ("plow pose") and Viparita Karani ("legs up the wall pose") have been associated with significant increases in intraocular pressure in both healthy individuals and those with glaucoma.[9] After assuming Adho Mukha Svanasana ("downward facing dog") for one minute, healthy subjects' intraocular pressure increased from 17 mm Hg to 29 mm Hg, while those with glaucoma increased from 17 mm Hg to 28 mm Hg. In a different study by Baskaran,[10] healthy subjects who assumed an advanced Sirsasana (headstand pose) showed a 2-fold increase in intraocular pressure for the duration of the posture. Thus, when considering physical activity recommendations with the goal of reducing intraocular pressure for patients with primary open-angle glaucoma, clinicians should use caution with including activities such as weightlifting and yoga.

Several studies have demonstrated a reduction in intraocular pressure associated with aerobic cardiovascular activity, which supports aerobic exercise as a potential management strategy for patients with primary open-angle glaucoma.[11-22] This effect has been observed for subjects who are young and elderly, sedentary and active, and with normotensive pressure and those with ocular hypertension or glaucoma.[22] For example, Najmanova et al.[11] recently investigated the effect of aerobic exercise on intraocular pressure for healthy, but sedentary young adult subjects. Immediately following moderate exercise on a bicycle ergonometer, intraocular pressure was reduced significantly relative to the subjects' resting baseline by approximately 18%. Similarly, Esfahani assessed the acute effect of a pre-programmed treadmill exercise program on intraocular pressure for a cohort of older subjects with suspected coronary artery disease.[12] Five minutes after completing the exercise program, intraocular pressure was reduced significantly by approximately 15%. Thus, aerobic exercise of mild to moderate intensity appears to acutely reduce intraocular pressure by a statistically and clinically-significant degree.

The effect of aerobic exercise of differing intensities has also been a topic of interest in ophthalmic literature. In a study by Qureshi,[13] both healthy subjects and those with glaucoma showed significant reductions in intraocular pressure during walking, jogging, and running, with the more intense exercises showing a more significant reduction in intraocular pressure relative to baseline. This study did not control for the variable amounts of work performed in during trial, which differed considerably. In a follow up study, Qureshi[14] confirmed that increased exercise intensity was associated with larger reduction in intraocular pressure in young, healthy, but sedentary male subjects. Conte et al.[15] compared the effects of a continuous moderate intensity exercise session versus a high intensity interval program on intraocular pressure for healthy, physically active young adult subjects. Immediately following exercise, both programs reduced intraocular pressure significantly by approximately 25% relative to baseline; however, at 10 minutes post exercise intraocular pressure had returned to baseline for the continuous moderate intensity group, while intraocular pressure remained significantly reduced for the high intensity interval group. As such, based on previous studies, higher intensity aerobic exercise may provide additional benefits in either magnitude or duration relative to low or moderate intensity exercise.

The purpose of the present study was to determine the acute effect of three different exercise intensities corresponding to 95%, 65%, and 45% of estimated maximal oxygen uptake on intraocular pressure in young, healthy subjects. Duration of effect was not assessed as part of this study. Based on previous studies, the authors hypothesized that intraocular pressure would be significantly reduced for all exercise intensities relative to baseline and that reduction in intraocular pressure would be associated with exercise intensity, that is, the higher exercise intensities would correspond to larger reductions in intraocular pressure relative to baseline.

Methods

Twenty-five healthy but sedentary young adults (10 male, 15 female; 20.40 +/- 1.10 years of age, 170.38 +/- 8.50 cm stature, 69.05 +/- 15.16 kg mass) with normal intraocular pressure (17.2 +/- 3.9 mmHg) participated in the study. Participants had no known diagnosis of ocular hypertension, glaucoma, or other ocular pathology. Participants were asked to avoid caffeine and exercise for at least five hours prior to the study; they also did not wear contact lenses for the duration of testing. This study was approved by the Pacific University Institutional Review Board (IRB 083-17).

Following completion of informed consent, baseline heart rate, blood pressure, and intraocular pressure were measured following a 15 minute seated rest period. Participants then completed the Queens College Step test to attain their estimated maximal oxygen uptake.[23-24] For the Queens College Step test, subjects stepped up and down on a step 41.25cm high for 3 minutes at a cadence of 24 steps/minute for men and 22 steps/minute for women. Cadence was maintained via an electronic metronome set at 96 beats per minute for men and 88 beats per minute for women. After a 15 second trial to adjust to the cadence, subjects maintained the stepping routine for 3 minutes. Within 5 seconds of completing the 3 minute step trial, heart rate was measured for 15 seconds while standing and multiplied by four to determine the recovery heart rate in beats per minute. This recovery heart rate value was used to calculate the estimated maximal oxygen uptake as follows: for men, estimated maximal oxygen uptake = 111.33 – (0.42 x recovery heart rate); for women, estimated maximal oxygen uptake = 65.81 – (0.1847 x recovery heart rate). The American College of Sports Medicine metabolic equation for running was used to determine treadmill speed based on each individual's estimated maximal oxygen uptake as determined by the Queens College Step test. Per the American College of Sports Medicine Resource Manual for Guidelines for Exercise Testing and Prescription, maximal oxygen uptake running = resting component + horizontal component + vertical component or maximal oxygen uptake running = 3.5 + 0.2 (speed) + 0.9(speed)(grade). Treadmill speed was the variable changed to achieve the exercise intensity appropriate to achieve an equivalent of 95%, 65%, and 45% of a subject's estimated maximal oxygen uptake, corresponding to low, moderate, and high intensities.[24] In a random and repeated design, participants completed 2.0 km at each exercise intensity level in a counter balanced manner. The duration of testing varied based on the treadmill speed. Heart rate was measured continuously throughout the duration of testing to ensure subjects maintained an appropriate level of exercise intensity. A running average of six intraocular pressure applanation measurements were taken from each eye following the completion of the 2.0 km (time 0) using the Icare ic100 tonometer (Tiolat Oy, Helsinki, Finland) as well as heart rate, and blood pressure. Additionally, Borg's scale of perceived exertion, a subjective perceptual rating of effort, was assessed immediately upon completion of each exercise condition.[25] Borg suggested scores of 11, 13, and 15 for "fairly light," "somewhat hard," and "hard" effort, corresponding to low, moderate, and high intensity exercise, respectively. Intraocular pressure, heart rate, and blood pressure continued to be measured at times 5, 10, and 20 minutes post exercise to ensure all parameters returned to baseline before proceeding with the next exercise program. Participants rested for at least 20 minutes or until heart rate returned to baseline (± 10%) before continuing on to the next exercise intensity level. If heart rate had not reached baseline within 20 minutes, intraocular pressure, heart rate, and blood pressure continued to be measured every 10 minutes until it reached baseline. Left and right eye intraocular pressure measurements for each time interval were averaged into a single reading that was used for statistical analysis since there was no difference between eyes using a 2 factor within subjects ANOVA with intensity and eye as repeated factors. A repeated measures one-way analysis of variance with post hoc tests analyzed time 0 intraocular pressure measurements for each of the four conditions (baseline, 45% maximal oxygen uptake, 65% maximal oxygen uptake, and 95% maximal oxygen uptake).

Results

The mean estimated maximal oxygen uptake for all subjects was 47.1 mL/kg·min (+/-12.0). Average resting baseline heart rate for all subjects was 68.6 (+/- 8.7) beats per minute with an average resting blood pressure of 118 mm Hg/75 mm Hg. Heart rate immediately following completion of the exercise program was 175.8 bpm (+/17.8), 147.8 bpm (+/-19.4), and 117.7 bpm (+/-16.4) with average participant walking/running speeds of 206.1 meters/minute (m/min), 135.5 m/min, and 88.4 m/min for 95% maximal oxygen uptake, 65% maximal oxygen uptake, and 45% maximal oxygen uptake, respectively. Average Borg rating of perceived exertion was 16.1, 12.5, and 9 for the high, moderate and low intensities, respectively.

Average intraocular pressure measurements for each condition are summarized in Table 1. A two

Table 1. Summary of Subject Speed, Heart Rate, Borg Perceived Exertion, and Intraocular Pressure for Different Exercise Intensities

Intensity	Speed (m/min)	Heart Rate (beats per minute)	Borg Perceived Exertion	Intraocular Pressure Right (mmHg)	Intraocular Pressure Left (mmHg)	Average Intraocular Pressure Both Eyes (mmHg)	Intraocular Pressure % Change from Baseline (mmHg)
Baseline		69		17.6	16.8	17.2	
95% Maximal Oxygen Uptake	206.1	175.8	16.1	13.1	12.7	12.9*	25
65% Maximal Oxygen Uptake	135.5	147.8	12.5	15.1	14.8	15.0*	12.8
45% Maximal Oxygen Uptake	88.4	117.7	9	16	15.4	15.7*	8.7

* p<0.01 relative to baseline

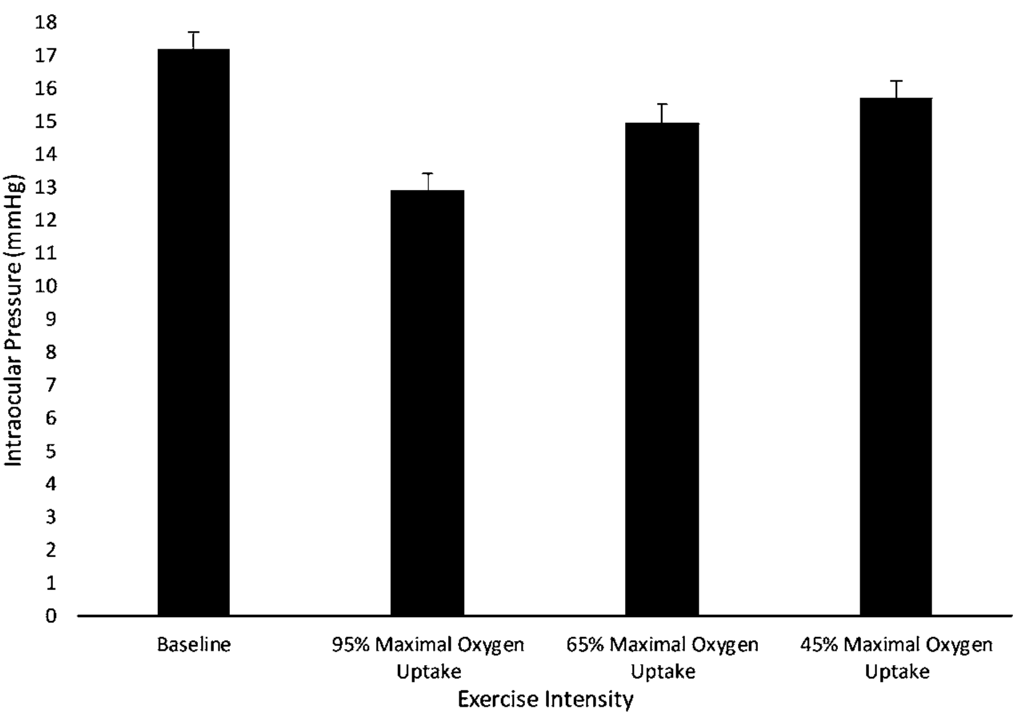

Figure 1. *Effect of Exercise Intensity on Intraocular Pressure. Plotted is mean intraocular pressure +/- 1 Standard Error of the Mean*

factor within subjects ANOVA with intensity and eye as repeated factors determined that there was no significant difference between eyes for any condition. Pearson correlation between eyes for baseline, 95% maximal oxygen uptake, 65% maximal oxygen uptake, and 45% maximal oxygen uptake were 0.941, 0.769, 0.716, and 0.866, respectively. Average baseline intraocular pressure for all subjects was 17.2 mm Hg compared to 12.9 mm Hg, 15.0 mm Hg, and 15.7 mm Hg immediately following exercise for 95% maximal oxygen uptake, 65% maximal oxygen uptake, and 45% maximal oxygen uptake, respectively, corresponding to reductions from baseline intraocular pressure of 25%, 12.8%, and 8.7%, respectively (Figure 1). Intraocular pressure was significantly reduced for all exercise intensities relative to baseline ($F_{3,72} = 30.25$, $p<0.01$). Cohen's effect size relative to baseline was 2.64, 1.36, and 0.91 for the 95%, 65%, and 45% maximal oxygen uptake conditions, respectively. The 95% maximal oxygen uptake intensity demonstrated significant intraocular pressure reduction relative to both the 65% maximal oxygen uptake and 45% maximal oxygen uptake intensities ($p = 0.001$, $d=1.28$ and $p = 0.009$, $d=1.73$; respectively). There was no significant difference between intraocular pressure for the 65% and 45% exercise intensities ($p=0.781$, $d=0.45$).

Two factor repeated measures ANOVA with intensity as repeated measure and gender as between subjects showed no significant difference between the intraocular pressure of male and female subjects for any condition.

Discussion

The current study investigated the effect of aerobic exercise corresponding to 95%, 65%, and 45% of estimated maximal oxygen uptake on intraocular pressure in a cohort of young, healthy subjects without glaucoma. Aerobic exercise at all intensities significantly reduced intraocular pressure relative to baseline. These findings are consistent with results of several previous investigations as summarized in Table 2.[11-22] Najmanova et al.[11] compared resting intraocular pressure of forty one healthy subjects before completing 30 minutes of moderate to high intensity exercise on a bicycle ergonometer corresponding to

Table 2. Summary of Literature Related to the Effect of Cardiovascular Exercise on Intraocular Pressure

Authors	Subjects	Exercise Intensity	Summary of Exercise Protocol	Change in Intraocular Pressure Immediately Following Exercise
Najmanova et al (2016)11	41 healthy young adult men and women	Moderate to High	Cycle ergonometer corresponding to an intensity of approximately 2 km per 5 min by the resistance force 12 N for 30 minutes	Intraocular pressure decrease
Esfahani et al (2017)12	patients with suspected coronary artery disease between 30-70 years	Not specified	Pre-programmed treadmill exercise program, parameters not specified	Intraocular pressure decrease
Qureshi (1995)13	14 middle aged males (7 with glaucoma, 7 without glaucoma)	Low, Moderate, High	Walking for 60 minutes, Jogging for 60 minutes, Running to volitional exhaustion	Intraocular pressure decrease for all intensities; larger reduction with higher intensity
Qureshi et al (1996)14	25 healthy sedentary young adult males	Low, Moderate, High	15 minutes on cycle ergonometer at 80%, 60%, and 40% of maximum heart rate; 7.5 minutes at 80% maximum heart rate, 10 minutes at 60% maximum heart rate, 30 minutes at 40% maximum heart rate	Intraocular pressure decrease for all intensities; larger reduction with higher intensity
Conte et al (2014)15	15 healthy young adult men	Moderate, High	Continuous moderate exercise for 30 minutes, High intensity interval training for 30 minutes	Intraoculr pressure decrease for all intensities; larger reduction with higher intensity
Qureshi (1996)16	32 sedentary males	Moderate	Cycle ergometer at a rate of on a 50 cycles/ min at a constant work load of 75 W for 60 minutes	Intraocular pressure decrease with low resistance sprints; increase with high resistance sprints
Najmanova et al (2018)17	24 healthy young women	High (anaerobic)	Maximal Exercise Test (progressively increasing speed up to 13 km/h, then increase in incline gradient until exhaustion)	Intraocular pressure increase; high variability in response
Vera et al (2017)18	26 physically active collegiate men	High (anaerobic)	Maximal cycling sprint against low and high resistance	
Vera et al (2018)19	24 physically active collegiate men and women	High	Low-fatigue and high-fatigue high intensity interval sprints	Intraocular pressure decrease with both high and low fatigue sprints
Rufer et al (2014)20	21 healthy young men and women	Moderate to High	Cycle ergonmeter with heart rate maintained at 170 beats per minute for 30 minutes	Intraocular pressure decrease

an intensity of approximately 2 km per 5 min by the resistance force 12 N. Immediately following exercise, intraocular pressure was reduced significantly relative to resting from 15mmHg to 12.3mmHg, corresponding to an intraocular pressure reduction of 18%. Similarly, Qureshi[13] observed intraocular pressure reductions of approximately 16% and 25% after completing 60 minutes of walking and jogging, respectively, for 7 middle aged subjects without glaucoma. In the same study, patients diagnosed with glaucoma showed higher intraocular pressure reductions relative to baseline with approximate reductions of 23% and 33% following 60 minutes of walking and jogging, respectively. Unfortunately, the parameters of exercise intensity (e.g. distance, pace, heart rate, maximal oxygen uptake) were not controlled nor specified in this study. Regardless, the reduction in intraocular pressure following aerobic exercise stated in the literature is consistent with the findings of the present study, which showed an intraocular pressure reduction of approximately 13% and 25% for moderate and high intensity aerobic activity, respectively, for a cohort of healthy, young-adult subjects without glaucoma.

Consistent with several previous studies, a more significant intraocular pressure reduction was observed during high intensity aerobic activity relative to both low and moderate intensity exercise in the present study. Qureshi et al.[14] evaluated the effect of aerobic exercise at different 3 intensities on intraocular pressure for 25 sedentary, young-adult male subjects. Relative to baseline resting intraocular pressure, reductions of 33%, 25%, and 6% were measured 5 minutes after completing 15 minutes of aerobic exercise on a bicycle ergonometer at 80%, 60%, and 40% of maximum heart rate, respectively. Interestingly, changes in intraocular pressure did not correlate with changes in systolic and diastolic blood pressure and therefore appear to be influenced by a factor independent of blood pressure. Regardless of the underlying mechanism, higher intensity exercise appeared to provide larger reductions in intraocular pressure. In contrast, a more recent study by Conte[15] investigated whether high intensity interval training provided superior intraocular pressure reduction relative to continuous moderate exercise for a cohort of 15 healthy young-adult men without glaucoma. The high intensity interval training exercise was performed for 30 minutes with 2 minutes of walking at 50% of reserve heart rate being alternated with 1 min of running at 80% of reserve heart rate. The continuous moderate exercise required subjects to run or jog for 30 min at 60% of reserve heart rate. The resting baseline intraocular pressure was compared to intraocular pressure measurements taken immediately following the exercise, as well as at 5 and 10 minutes post-exercise. For both the high intensity interval training and continuous moderate exercise trials, intraocular pressure was reduced significantly relative to baseline immediately following exercise, as well as 5 minutes post-exercise. Intraocular pressure reductions between the high intensity interval training and continuous moderate exercise did not differ significantly from each other immediately following exercise or 5 minutes post-exercise; however, intraocular pressure remained significantly reduced relative to baseline following the high intensity interval training trial whereas intraocular pressure returned to baseline levels at 10 minutes post-exercise for the continuous moderate exercise trial. Thus, based on the results of the present study and similar previous studies, relative to low and moderate intensity aerobic exercise, high intensity exercise likely provides additional intraocular pressure reduction benefit in terms of magnitude, duration, or both.

Maximal oxygen uptake represents the maximum oxygen an individual can utilize during intense exercise and is considered to be the gold standard for expression of cardiorespiratory fitness.[26] A higher maximal oxygen uptake is generally considered to indicate better cardiorespiratory fitness. Previous work has found that sedentary individuals attained a larger acute intraocular pressure reduction than fit individuals following exercise.[22] For example, in a different study by Qureshi,[16] 32 sedentary, young-adult male subjects were divided into either a control group or experimental group that completed a 3-month supervised exercise program that included running for 1 hour in the morning and playing hockey for 1 hour in the evening, five days per week. Each subject had intraocular pressure measured before and after completing 1 hour of pedaling an ergometer bicycle continuously at a rate of on a 50 cycles/ min at a constant work load of 75 W at both baseline as well as following completion of the supervised exercise program for 3 months. At baseline, the acute intraocular pressure reductions following the 60 minute cycling exercise test were 4.18 mm Hg and 4.38 mm Hg, while after 3 month training program these values were 4.12 mm Hg and 2.69 mm Hg in control and experimental groups, respectively. Thus, while both the experimental and control groups experienced a significant reduction in intraocular pressure following 60 minutes of cycling, the more physically fit experimental group showed a smaller reduction in intraocular pressure post-exercise relative to pre-exercise levels. The mechanism by which more physically fit individuals experience an altered intraocular pressure response following exercise relative to more sedentary individuals is not clear.

Several theories have been proposed to explain the mechanism of intraocular pressure reduction following exercise.[22] Hypocapnia, that is, reduced serum carbon dioxide that results from heavy breathing or hyperventilation, has been shown to produce ocular hypotension in isometric exercise (e.g. strength training); however, in more dynamic aerobic exercise, prevention of hypocapnia with carbon dioxide addition failed to lessen the decrease in intraocular pressure.[27-28] Similarly, adrenergic stimulation as an underlying mechanism for exercise induced ocular hypotension has been discounted as the use of adrenergic beta blockers during exercise did not prevent hypotension. Martin et al.[29] found that an increase in colloid osmotic pressure related to capillary ultrafiltration (e.g., dehydration of the eye through osmotic changes in the retinal and uveal vasculature) correlated closely with acute intraocular pressure reductions during exercise and therefore has been proposed as a likely mechanism for exercise induced hypotension.

There are several limitations in the current study that should be considered in future work. First, the iCare tonometer may be influenced by corneal thickness, a parameter not assessed in the current study.[30] Secondly, the sample size of the current study is relatively small and consisted of young, healthy subjects. Future studies should seek to investigate the effects on patients with glaucoma or those at higher risk for developing the condition. Third, although the authors sought to minimize a fatigue/training effect by allowing ample rest time between trials as well as utilizing a counter-balanced randomization process, it is possible that previous trials may influence subsequent trials in a repeated measures design. Fourth, while previous work has shown the accuracy of prediction of the Queens College Step Test to be +/- 16% of the measured values, no actual gas exchange was measured during the current study.[23] Measurement of maximal oxygen uptake in a laboratory setting requires specialized equipment and, as such, the step test provides a reasonable approximation of maximal oxygen uptake. Finally, there is a well-established diurnal change in intraocular pressure, particularly during sleeping hours, which was not controlled for in the current study.[31-32] Future studies in this area should attempt to collect data at the same time each day to better control for intraocular pressure fluctuations related to diurnal variation. While not specifically evaluated in the current study, the duration of effect should be a focus of ongoing research in this area as previous work has demonstrated a wide range of duration of effect ranging from as little as 10 minutes to nearly 1.5 hours, depending on various factors, such as resting/baseline IOP, presence/absence of glaucoma, and exercise intensity.[14-15]

Despite the limitations above, the results of the present study suggests that aerobic exercise should be considered as part of the therapeutic options for patients with glaucoma or those at risk of developing the condition who are interested in lowering their intraocular pressure through non-pharmaceutical or non-surgical means; however, more investigation is needed to determine the long term effects of aerobic exercise on IOP and subsequently, glaucoma progression. Higher intensity aerobic exercise produces more significant reductions in intraocular pressure and therefore may be more advantageous for patients interested in lowering their intraocular pressure, however, many patients with glaucoma, which tends to affect older populations, may not be physically capable to performing high intensity exercise. It is notable that statistically and clinically significant intraocular pressure reductions of 8.7% and 12.8% were observed for the low and moderate intensity exercise programs, so even light cardiovascular activity such as walking or light jogging are likely to confer intraocular pressure reduction benefits for patients who are physically capable. It is possible that the effects of small bouts of activity throughout the course of the day, for example taking the stairs rather than an elevator or choosing a parking spot further away from the building entrance, may produce transient reductions in intraocular pressure over the course of an entire day, which may cumulatively be significant in reducing average daily intraocular pressure, the only modifiable risk factor for glaucoma at present.

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