

Maximal incremental exercise improves macular photostress recovery time and lowers intraocular pressure in healthy athletes

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ABSTRACT

Objectives: Better visual performance in athletes compared to non-athletes could suggest improved macular function through physical exertion. The study aimed to investigate the effect of maximal incremental treadmill (MIT) exercise on macular function.

Design: An interventional study comparing the effect of maximal incremental treadmill (MIT) exercise until volitional exhaustion between athletes (n=26) and non-athletes (n=26).

Methods: Participants underwent an ophthalmological assessment involving repeated measurements of the photostress recovery time (PSRT) at baseline and post-exercise. PSRT was recorded after a 10-second exposure of the macular to an intense light source from an ophthalmoscope positioned 2 cm in front of the eye. Secondary outcome measures also recorded included the best-corrected visual acuity (BCVA) and the intraocular pressure (IOP).

Results: Compared to the baseline, MIT exercise markedly improved the PSRT of athletes from 42.7 ± 1.6 seconds to 39.6 ± 1.4 seconds ($P < 0.001$), while having no significant changes in the PSRT of non-athletes. After adjusting for exercise duration, the exercise intervention showed significant effects on the PSRT improvement in the athletes compared to non-athletes after exercise [$F(1,49)=16.941$, $P < 0.001$], with estimated marginal means of 3.00 seconds and 0.47 seconds, respectively. Also, the exercise intervention resulted in significant improvements in IOP ($P < 0.001$) and BCVA ($P < 0.01$) of both groups.

Conclusions: MIT exercise improves macular function, BCVA, and reduced IOP in healthy athletes. Maximal incremental exercise may be recommended for competitive sports athletes seeking optimal visual performance, as long as it does not adversely impact other relevant non-visual factors.

Keywords: physical exercise; neuroprotection; visual performance; intraocular pressure; retinal microcirculation.

1. Introduction

Exercise is becoming a more popular healthy lifestyle behaviour following the understanding of the mechanisms behind the widespread health benefits associated with higher physical activity.¹ Regarding eye health and vision, physical exercise exerts numerous physiological effects which include changes in the ocular blood flow rate and perfusion pressure, choroidal thickness, retinal function, and intraocular pressure (IOP).²⁻⁵ Since higher IOP causes mechanical compression of the optic nerve and retinal blood supply, leading to impaired axoplasmic flow and optic nerve ischemia,⁶ the IOP-lowering effect of physical exercise is neuroprotective in glaucoma.⁶ Also, physical exercise has been observed to reduce the risk of age-related macular degeneration, primarily caused by the oxidative damage of retinal pigment epithelium.^{7,8} These pieces of evidence directly or indirectly corroborate the physiologic impact of physical exercise on retinal function and homeostasis.

Woods and Thomson earlier reported significant improvement in contrast sensitivity (CS) after cycling and jogging but not after stair running.⁹ They argued, however, that the changes could be related to a shift in the decision criteria instead of actual changes in the retinal sensitivity.⁹ Thereafter, several other researchers confirmed changes in monocular and binocular visual functions in healthy normal and amblyopic eyes, including static and dynamic visual acuity, stereoacuity, accommodative facility, and the near point of convergence, after exercise.¹⁰⁻¹⁴

Based on the evidence backing improved visual performance with exercise, the current study hypothesized that physical exercise enhanced macular function in healthy eyes. Hence, the purpose of the study was to investigate the changes in photostress recovery test (PSRT; a good index of macular function), and IOP after a single session of physical exercise. The PSRT is a simple clinical test employed in the assessment of retinal (or macular) function and can be used

for differentiating macular diseases from post-retinal (e.g. optic nerve) disorders.^{15,16} The test measures the time taken to regain baseline visual acuity after the light-sensitive visual pigments of cone photoreceptors have been bleached by intense white light exposure to the macular.¹⁶ Athletes and non-athletes were enrolled into the study due to the emerging evidence that fitness levels may lead to differential physiological responses to exercise stress, in terms of systemic measures, such as heart rate, blood circulation and pressure, and inflammation,^{17,18} as well as oculo-visual changes in tear secretion, inner retinal signaling, and ocular perfusion.^{4,19,20}

2. Methods

Ethical approval for the study was granted by the Institutional Review Board of the University (UCCIRB/CHAS/2015/046). Informed consent was given by participants before the study and they retained the right to withdraw from the study at any point in time. A health screening was initially conducted on all volunteers to make sure they were in good health and could participate. Additionally, a medical team was on-site to provide first aid and to handle emergencies if any arose. The guidelines stipulated in the Declaration of Helsinki for the use of human research subjects were adhered to.

A before-and-after interventional study was conducted to investigate the effect of a single bout of physical exercise on the macular function and IOP of athletes and non-athletes. Fifty-two university students were recruited into two groups: athletes ($n = 26$) and non-athletes ($n = 26$). This meets the minimum sample size of 52 (G*Power software) required to determine a difference in the PSRT between two independent means, with an effect size of 0.8 (based on the previous study by Zwierko et al)⁴, 5% ($p = 0.05$) significance level, and 80% power. Those classified as athletes belonged to the University Sports Team and participated in sports activities, including field tracks and soccer, for ≥ 6 months. Individual members of the group

reported exercising regularly (5 times/week and >45 mins/session). The non-athletes were students who reported exercising for not more than three times/week and less than <30 mins/session. Upon establishing that one was fit to participate by health screening, a preliminary eye examination was conducted to determine that the unaided distance Snellen VA before correction was 6/7.5 or better, and the spherical equivalent refractive correction did not exceed $\pm 0.50D$ in either eye. Thus, only persons with normal vision and who had no need for refractive correction were recruited. Those detected as having media opacity, retinal disorders, glaucoma, or any form of optic nerve atrophy were also excluded. Additionally, none of the participants had a history of chronic systemic disease, including diabetes and hypertension, or was on any medical treatment.

The study was carried out at a gymnasium under a temperature of 28.2 ± 0.3 °C and relative humidity of $89 \pm 2.7\%$. The impact of diurnal variation was minimized by taking all measurements around the same time of the day and the experiment was completed within 2 hours. Baseline ocular measurements, including best-corrected distance visual acuity (BCVA), IOP and PSRT, were taken after a 20-min sitting period. The post-intervention measurements were taken 10 mins after completing the treadmill exercise in order to allow the return of breathing rate to normal and improve the accuracy of subjective responses to the PSRT. Details about the study protocol are described as follows.

For the maximal incremental treadmill (MIT) exercise, the eligible participants had to avoid the intake of caffeine 2 days before the study, as the stimulant affects vision and neuro-ophthalmic responses.²¹ To promote the optimal performance of exercise, participants were given 500 ml of water to drink all at once an hour before the exercise.²² The MIT exercise was done under the guidance of a qualified gym instructor following the Bruce treadmill test, as previously described.¹⁹ Briefly, after a 10-minute warm-up, the actual running test commenced

at a speed of 2.74 km/h and 10% slope. The exercise intensity was increased (by adjusting the speed and slope) every 3 min until volitional exhaustion. The total time spent on the treadmill test in minutes was recorded and used in calculating the maximum oxygen uptake ($\text{VO}_{2\text{max}}$), a measure of cardiovascular fitness.¹⁹ Also, both the resting and maximal heart rate were documented for use in determining the degree of effort spent.

Participants' BCVA was measured monocularly without any glare source, using the LogMAR chart based on Bailey-Lovie designed at a test distance of 6 m. To record the visual acuity, the logMAR value of the best line completely read was first noted. Then, the number of additional letters read in the next row below was multiplied by 0.02 and subtracted from the logMAR value of the best line completely read. Next, the dominant eye was chosen for the assessment of the ocular measurements, including the PSRT and IOP. The ophthalmoscope light was used to conduct the photostress procedure in the undilated eyes as previously described.¹⁵ After that, the investigated eye was exposed to the bright light from the ophthalmoscope directed onto the macula for 10 seconds to induce photobleaching. It involved the positioning of the ophthalmoscope at 2 cm in front of the eye while instructing the participant to fixate on the light source. The ophthalmoscope was maximally charged before each test to avoid changes in luminance. Immediately following the removal of the ophthalmoscope, the participants were asked to read the letters just above their baseline acuity (i.e., Snellen VA 6/9 equivalent to) with the photobleached eye. The time taken to regain the ability to read all letters on that target VA line correctly was recorded using a stopwatch. Subsequently, the IOP was measured using the portable Tono-Pen Avia (Reichert Technologies, USA). A new Ocu-Film tip cover was placed at the tip of the Tono-Pen before taking the IOP of each participant. To record the IOP, a topical anesthetic (amethocaine) was instilled in the eye. The tonometer's button was pressed once for its light to turn green, and the central portion of the anaesthetized cornea was gently

tapped till a beep sound was heard. The IOP was then recorded in millimeters of mercury (mmHg). Three readings were taken and the average was recorded.

Prior to the study, the test-retest reliability for each of the ocular examination techniques was evaluated under similar conditions by conducting repeated measurements at baseline and 2 hours later, on the same individuals ($n = 10$). The coefficient of variation (CV) and the intraclass correlation coefficient (ICC) of the measurements supported very good intra-observer repeatability (CV ranges from 3.2 to 4.9%, ICC ranges from 0.89 to 0.96).

The statistical analysis of data was performed with Statistical Product for Service Solutions (SPSS, Version 21; Chicago, Illinois, USA), and graphs were plotted with GraphPad Prism (Version 9.0; San Diego, CA, USA). Within-group differences were determined using paired sample *t*-test. Between-group differences were analyzed either by the independent *t*-test, or Analysis of covariance (ANCOVA) to control for the effect of exercise duration as a covariate. Statistical significance was established when the *p*-value ≤ 0.05 .

3. Results

The participants in this study were aged between 18 and 25 years, with the mean age (\pm SD) of the athletes and non-athletes being 22.4 (\pm 2.1) and 21.8 (\pm 2.1) years, respectively ($P = 0.357$, independent *t*-test). The non-athlete group had a higher number of males (17/9) compared to the athlete group (13/13), but this difference in sex distribution was not statistically significant ($\chi^2 (1) = 1.261$, $P = 0.400$). When comparing their performance in the MIT exercise, it was found that the athletes ran for an average of 13.3 ± 2.1 min before reaching exhaustion, whereas the non-athletes lasted an average of 8.7 ± 2.1 min ($P < 0.001$). The predicted VO_2 max (ml/kg/min) measurements validated that male and female athletes were more physically fit

than their sex-matched non-athlete counterparts. Specifically, the male athletes had a VO_2 max of 55.1 ± 4.9 compared to 34.3 ± 4.8 in non-athletes ($P < 0.001$). Similarly, the female athletes had a VO_2 max of 40.6 ± 3.7 ml/kg/min, while the non-athletes had a VO_2 max of 29.7 ± 3.4 ($P < 0.001$, independent t-test). The resting heart rate (beats/min) for athletes was significantly lower compared to non-athletes (56.2 ± 5.3 vs. 64.5 ± 5.9 , $P < 0.001$). However, no significant difference was found in their maximal heart rate (196.5 ± 5.6 vs. 194.8 ± 4.8 , $P = 0.246$). Both groups were similar in terms of body weight, with the athletes having an average weight of 69.8 ± 6.8 kg and the non-athletes having an average weight of 70.5 ± 7.7 kg ($P = 0.733$, Table 1).

<Insert table 1>

Before the exercise intervention, the two groups were not significantly different in any of the ocular parameters studied. Within-group analysis showed that exercise induced a significant decline in the IOP of both athletes (15.9 ± 1.5 mmHg to 14.1 ± 1.7 mmHg, 11.3%; $P < 0.001$, paired *t*-test) and non-athletes (16.1 ± 2.2 mmHg to 14.5 ± 2.2 mmHg, 10.6%; $P < 0.001$) compared to baseline. Likewise, exercise led to an improvement in the BCVA of athletes (logMAR 0.014 ± 0.033 to logMAR -0.021 ± 0.029 , $P < 0.001$) and non-athletes (logMAR 0.022 ± 0.040 to logMAR -0.003 ± 0.039 , $P = 0.009$). For the PSRT, exercise led to a marked reduction in the vision recovery time to bright light exposure in the athletes (42.7 ± 1.6 seconds and 39.6 ± 1.4 seconds, 7.2%; $P < 0.001$, paired *t*-test) but not in nonathletes (43.3 ± 1.4 seconds to 42.8 ± 1.8 seconds, 1.2%; $P = 0.197$).

One-way ANCOVA was conducted to determine whether after adjusting for exercise duration, MIT exercise intervention produced different effects on the ocular measures in the two groups. The results indicated no significant difference in the mean IOP reduction [$F(1,49)=1.998$, $P = 0.164$] and the mean BCVA [$F(1,49)=0.172$, $P = 0.680$] after exercise between the groups.

Conversely, the exercise intervention had significant effects on the improvement of PSRT in the athletes compared to nonathletes after exercise [$F(1,49)=16.941, P < 0.001$], with estimated marginal means of 3.00 seconds and 0.47 seconds, respectively.

4. Discussion

Current research indicates that physical exercise could serve as a cost-effective approach to lowering (IOP) and protecting against vision loss caused by glaucoma.⁶ Furthermore, anecdotal evidence regarding changes in visual performance due to physical exercise supports the hypothesis of potential alterations in macular function. The present study provided evidence that a single session of MIT exercise intervention in athletes yielded significant benefits in terms of IOP control and optimal macular function, evident from the notable improvements observed in the PSRT and BCVA measures. Similar changes were also observed in the nonathletes after exercise, except for the PSRT. So far as neural activity in the macular/outer retina (including the RPE and photoreceptors) is concerned, this is the first study to elucidate the impact of physical exercise on macular function.

In this study, the average baseline PSRT for all participants was around 40 seconds. While this falls within the normal range of 10-50 seconds typically observed in healthy individuals,²³ it seems slightly higher for the specific age group of 18-25 years compared to similar populations in previous research.²⁴ The difference in the PSRT between studies has been attributed to the lack of standardization in the intensity, duration of light exposure, lighting source and type, room illumination, and factors related to the endpoint of the test.^{15,25} However, it is clear that interobserver variabilities in ocular parameters, including pupil size, ametropia, and visual acuity, do not play a significant role apart from age.¹⁵

Physical exercise was found to improve PSRT, a reliable macular function index,²⁵ as well as BCVA in athletes. The existing literature shows that the PSRT is influenced by several extraneous and intrinsic factors some of which include macular pigmentation,¹⁶ retinal vascular perfusion pressure,²⁶ chronic smoking,²⁷ optical short-wave light filters,²⁸ carotenoid supplementation,²⁹ etcetera. Experimental evidence has shown that exercise increases retinal microcirculation and ocular blood flow possibly through nitric oxide upregulation.³ Hence, it is likely the improvement in PSRT and visual acuity after exercise is due to an increase in ocular blood flow. However, the specific increase in PSRT observed solely in the athletes after exercise can potentially be attributed to factors associated with the impact of "chronic" exercise, which may enhance the acute effects of exercise on ocular blood flow and retinal function. In fact, a recent study observed that a 10-min aerobic exercise in physically active volunteers yielded a greater choroidal volume compared to those of lower physical activity levels, emphasizing the additive effect of "chronic" exercise on the responses to acute exercise in the choroid.² Though no study had yet reported functional changes in the outer retinal layers (including photoreceptors and RPE) after acute exercise, previous studies using electrophysiology found changes in the b-wave amplitude, implicit time of b-wave, and oscillatory potentials in the, indicating functional changes in the inner retina.^{4,30} Also, we observed a 1.8 mmHg (or 11%) reduction in the mean IOP which was measured at 10 minutes after exercise. This is comparable to the 10-min post-exercise IOP data in the Hong et al. study which found a decline of 2.1 mmHg, after a 15-min treadmill run at a speed of 6.5-8 km/h.⁵ IOP measurement by Tono-Pen, a portable tonometry device, is reported to closely match the "gold standard" Goldmann applanation tonometry with an average difference of <1mmHg between them in a large sample.³¹ While the exercise intervention's impact on retinal (or macular) function improvement and IOP reduction is anticipated to be transient or short-term changes,⁴ it is important to note that the acute effects of exercise could play a significant role

in contributing to long-term alterations in these measures. These effects may accumulate over time, potentially leading to structural adaptations in the choroidal and retinal microvasculature, ultimately resulting in sustained changes in ocular functions.³

There were, however, a few limitations in the study. Firstly, the categorization of the participants into athletes and nonathletes was solely based on whether one belonged to the University's Sports Team or not. Notwithstanding that the athletes engaged in regular physical exercises, such as running and playing football, it is possible to have nonathletes who are also physically active due to their engagement in some kind of higher energy expending activity, like brisk walking, stairs climbing, etc.³² Hence, an estimation of the metabolic equivalents (METs), using the Compendium of Physical Activities, would have helped to properly determine the physical activity levels of individual participants.³² Also, this study was conducted in only healthy persons without any retinal abnormalities. Caution, therefore, must be applied regarding the extension of the findings to persons with retinal disorders.

5. Conclusion

The study findings demonstrate that maximal physical effort is associated with an improvement in the macular photostress recovery time in the eyes of healthy athletes. Thus, besides IOP reduction, being more physically active is beneficial for optimal retinal function and visual performance, and this is possibly mediated by increased ocular perfusion.

Practical implications

- The documented evidence of better visual performance in athletes can be explained based on the functional changes in the retina after physical exercise.

- Maximal incremental exercise may be recommended for competitive sports athletes seeking optimal visual performance, as long as it does not adversely impact other relevant non-visual factors.
- Young, healthy non-athletes can also experience the advantages of exercise, including the potential reduction in intraocular pressure and improvement in distance vision.

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Table 1: Participants characteristics and fitness measures

Characteristic	Athletes	nonathletes
Male/Female (no.)	13/13	17/9
Mean age (year)	22.4±2.1	21.8±2.1
Body weight(kg)	69.8 ± 6.8	70.5±7.7
Resting HR (beat/min)	56.2±5.3***	64.5± 5.9
Maximal HR (beat/min)	196.5±5.6	194.8±4.8
Exercise duration (min)	13.25 ± 2.08***	8.74 ± 2.12
VO ₂ max (ml.kg-1.min-1): Male	55.1 ± 4.9***	34.3 ± 4.8
Female	40.6 ± 3.7***	29.7 ± 3.4

***indicate p < 0.001, heart rate (HR)