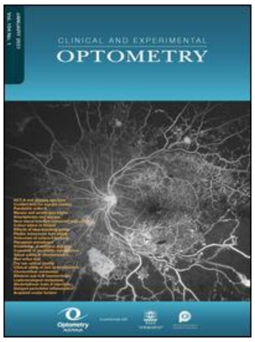

Clinical and Experimental Optometry

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tceo20

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To cite this article: Brandon S Shaw, Gerrit Breukelman, Lourens Millard, Jason Moran, Gregory Brown & Ina Shaw (2022): Effects of a maximal cycling all-out anaerobic test on visual performance, Clinical and Experimental Optometry, DOI: 10.1080/08164622.2022.2153583

To link to this article: https://doi.org/10.1080/08164622.2022.2153583

CLINICAL AND EXPERIMENTAL OPTOMETRY
https://doi.org/10.1080/08164622.2022.2153583

RESEARCH

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Effects of a maximal cycling all-out anaerobic test on visual performance

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ABSTRACT

Clinical relevance: All-out exercise may not impair all central nervous system processes, such as those related to visual-motor abilities, and may actually prove stimulatory to such tasks allowing athletes and sports conditioning specialists to develop strategies to take advantage of/mitigate the effects of such exercise on athletic performance.

Background: Despite research indicating that visual-motor abilities play a critical role in athletic performance, research has primarily focused on the effect of all-out exercise on processes along the motor pathway, such as resultant force production or simple cognitive tasks. Such research has neglected to investigate the effect of all-out exercise on visual tasks. When investigations on visual tasks are forthcoming, they focus on prolonged aerobic exercise, which is not the primary metabolic pathway for all, or even the majority of sports.

Methods: Sixty untrained males (experimental group; $N = 30$, control group; $N = 30$) completed a standardised six-item baseline sports vision test battery and one week later, the experimental participants returned to undertake a 30-second Wingate anaerobic test (30-WAnT) immediately followed by the same test battery.

Results: Significant ($P < 0.05$) improvements were found in accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness and hand-eye coordination ($P < 0.001$ for all), but not visual memory ($P = 0.242$) following the 30-WAnT.

Conclusions: Although the mechanisms underlying these improvements in visual task performance have not yet been studied, this study suggests that simple anaerobic all-out exercise does not cause central- or brain-based fatigue impairing the oculomotor system but may rather provide "excitability" of the underlying motor cortex, motoneurons and/or corticofugal connections utilised in visual task response. It appears that the sweeping improvements in visual task performance elucidate the need for an intense anaerobic warm-up when training visual skills and when visual skills form an integral part of athletic performance.

ARTICLE HISTORY
Received 14 June 2022
Revised 10 October 2022
Accepted 22 November 2022

KEYWORDS
Anaerobic threshold; anaerobiosis; exercise; muscle fatigue; psychomotor performance

Introduction

While most research has demonstrated the impact of physical activities on simple cognitive tasks, such research has neglected the effect of fatigue on other important tasks, such as visual tasks. Recent studies have shown that visual-motor abilities play a critical role in athletic performance.[1,2] It is for this reason that sport learning theory suggests that athletes need to assess and/or develop not only physical and motor abilities, but also visual and perceptual-cognitive skills.[3,4] In this way, the assessment and training of visual skills has aroused the interest of athletes, coaches, sport scientists and vision specialists.[5] Further, pre-season baseline testing to highlight any postinjury deficits (i.e. following concussion) has become increasingly prevalent in sports as baseline testing allows clinicians to gauge pre-injury performance.[6] Athletes are often administered these baseline tests while at rest, despite injuries routinely occurring and being immediately assessed during physical activity.[6] Therefore, adjustments are required to baseline testing to account for any modifying factors that may jeopardise not only performance outcomes, but also injury assessments.[7]

While fatigue is commonly associated with deleterious physical and cognitive performance, previously, it has been demonstrated that different types of metabolic fatigue, induced by anaerobic alactacid, anaerobic lactacid, sub-maximal aerobic, and maximal aerobic efforts have improved performance of a sensory task (peripheral threshold detection), a sensory-motor task (coincidence-anticipation), and a cognitive task (recall in central vision).[8] These differences in the effect of fatigue on physical, cognitive or visual performance may be related to central or peripheral origins of fatigue.[9]

Studies have demonstrated that induced fatigue may result in deterioration in some visual skills.[10] This decrease in visual skill has purported to be as a result of prolonged exercise causing central- or brain-based fatigue in the corticospinal motor system, which in turn, may impair the oculomotor system.[10] Previously, a systematic narrative review showed that vision and cognitive disturbances were induced immediately following aerobic exercise bouts.[11] Additionally, a 20-minute interval fatigue protocol, utilising running, stepping and calisthenic exercises, has demonstrated that fatigue affects vestibular, and/or the ocular motor system.[12] Further, maximal aerobic capacity exercise has shown to decrease decision-making time while simultaneously increasing decision-making errors in athletes.[13] While strenuous prolonged aerobic exercise has been reported to affect various aspects

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of visual function, exercise modality appears to have varied effects. Specifically, while cycling, jogging and stair running have no effect on visual acuity, refractive error, dark focus, amplitude of accommodation or pupil size, contrast sensitivity was found to improve after cycling and jogging, but not after stair running.[14] While much research focuses on the effect of prolonged aerobic exercise, this mode is not the primary metabolic pathway for all, or even the majority of sporting codes. While fatigue have been explored following long-duration running or cycling,[15] the type of fatigue induced by a short cycling bout is understudied,[16] nor have its effects on sports-specific visual task performance. This is particularly important when evaluating the effects of exercise on visual function or evaluating the efficacy of vision training. Further, although these studies provide interesting information about the accumulative effect of several cycling bouts over the muscle fatigue mechanisms, it is still unknown how a single and maximal cycling all-out test affects fatigue.[17]

Problematically, vision has a multitude of definitions in literature with none being as being as simple as only seeing.[5] To date, no research exists on how an all-out anaerobic effort affects visual task performance. Consequently, the objective of this study was to investigate the effects of a maximal cycling all-out test on the performance of several visual tasks. It was hypothesised that an acute maximal cycling all-out test would improve the performance of several visual tasks.

Methods

The study protocol was reviewed and approved by the Institutional Review Boards of the University of Zululand (UZREC 171,110-030-PGD-2021/27) and complied with the tenets of the Declaration of Helsinki as revised in 2013. All participants provided oral and written informed consent.

Study participants

Sixty males participated in the study (mean age: 23.11 ± 3.02 years). The inclusion criteria for the study was that the participant had to have a minimum of 20/20 vision (either unaided or corrected with soft contact lenses during the experiment), they should not have participated in any form of structured sport or exercise regime for the past six months, and none of the participants should have had previous experience with sport vision testing.[17] Participants were excluded from the study if they did not have 20/20 vision (either unaided or corrected with soft contact lenses during the experiment), had any form of visual disease or infection, physical disability and/or psychosocial distress[18] and if they presented with any relative or absolute contraindication to exercise or testing.[19] Participants received both written and oral information about the aims, data collection and data management of the project before providing written informed consent and were able to withdraw from the study at any time. Participants were randomly assigned using a random numbers table and divided into an experimental group ($N = 30$) or a control group ($N = 30$).

Procedures

Prior to participation in the study, participants underwent an optometric assessment to ensure 20/20 vision. Spectrum Eyecare software (Version 6.0.0, Digital Optometry, South Africa) was used to measure each participant's depth perception and visual acuity.

The study utilised the Hart Near Far Rock Test to assess accommodation facility, which is the function whereby the refractive power of the optical system of an eye can change, enabling images of both distant and near objects to be viewed clearly.[20] The large Hart Chart was placed 3 metres away from the participants on a board, at head height.[21] Participants were instructed to hold another smaller chart at arm's length away, after which they were tasked to read the first letter of the first line of the chart on the board three metres away and then proceed to read the first letter of the chart at arm's length away. Participants then read the second letter of the first line of the far chart, then the second letter of the first line of the near chart, and so forth for 30 seconds, after which the errors were subtracted from the score to determine the final score.[21]

To evaluate saccadic eye movement (rapid, ballistic movements of the eyes that abruptly change the point of fixation), the study utilised standardised saccadic eye movement charts.[22] Two charts were placed on a board, 1 metre apart, and 3 metres away from the participants and participants were instructed to read the first letter on the lateral side of the left chart, and then rapidly move their eyes and without moving their heads to the first letter on the lateral side of the right chart and read the first letter. The participant then altered focus to the second letter of the left chart once they had read the first letter of the left and right chart and this process continued for 30 seconds. At the conclusion of this test, errors were subtracted from the score to determine the final score. To ensure that participants could not memorise the letters, standardised, yet adjustable saccadic eye movement charts were utilised that had letters going down vertically on both sides of the page.[21]

Speed of recognition was measured by the Batak Pro, using the Evasion program.[23,24] This program lights the 12 LED lights randomly for 1 sec, and the participant was required to strike the target while still lit. If a target was lit but only flickered, participants were not to strike the target and if they did so, 5 points were deducted from the final score.[24] In turn, when all of the lights in the centre of the Batak Pro flickered, participants were required to evade the small central infrared beam and if caught by the beam, 5 points were deducted from the final score. All scores were automatically determined by the microcomputer with a maximum of 100 targets being illuminated.

Hand-eye coordination was evaluated using the Ball Wall Toss Test.[25] A mark was measured 2 metres away from a wall at which participants were required to throw a standard tennis ball, and catch it, while alternating hands for 30 seconds.[21] The amount of successful catches was recorded.

Peripheral awareness was measured using the Accumulator Programme on the Batak Pro.[23,26] In this programme, random LED targets illuminated, and remained illuminated until it was struck by the participant. After being struck, another LED target would immediately light up for a period of 60 seconds.[24] The Batak Pro microcomputer automatically calculated a final score at the end of the test.

Visual memory was assessed using the Flash Memory Programme on the Batak Pro.[24,27] In this program, 6 targets were lit for ½ second. Following this, participants were required to remember the 6 targets that illuminated, as well as the order in which they lit up.[24,28] The Batak Pro microcomputer calculated the maximum score at the end of the test.

After a week had passed following baseline visual task testing, participants underwent a 30-WAnT, immediately followed by the same test battery described above. The 30-WAnT was performed on a cycle ergometer (Model 834E, Monark Exercise AB, Vansbro, Sweden) as described by Inbar et al.[29] The 30-WAnT was preceded by a five-minute (min) warm-up at the inertial resistance of the equipment, including two bouts of four seconds performed in the final seconds of the second and fourth minutes. After a 10-min rest, the participants were instructed to pedal "all-out" for 30 sec against a resistance of 0.09 kg.kg^{-1} body mass.[29] Verbal encouragement was provided throughout the test. The external power output was calculated every 1 sec. The highest external power output in the first 5 sec of the test was used to represent the peak power (PP), whereas the average power generated over 30 sec was recorded as the mean power (MP).[29] In addition, the fatigue index (FI) is reported as the percentage decline from PP to the lowest power produced at the end of the test [(PP-lowest power) /PP × 100)].[29] Each participant was then required to begin the sports vision test battery immediately after completing the 30-WAnT. Control group participants returned to undertake the same test battery (without a treatment immediately beforehand) to determine if a learning effect occurred.

Statistical analysis

The Shapiro-Wilk Test was utilised to determine if the data was normally distributed. Dependent and independent t-tests were utilised to determine if any changes occurred at post-test both within- and between-groups, respectively. Hedges' correction was utilised to determine effect size between measures for baseline and after anaerobic treatment. The substantial effects for φ were divided into more fine-graded magnitudes as follows: $0.20 \leq \varphi < 0.50$ corresponded to a small effect size, $0.50 \leq \varphi < 0.80$ corresponded to a medium effect size, and $\varphi \geq 0.80$ corresponded to a large effect size. For all statistical analyses, the results were assumed to be significant at an alpha level of 0.05. The statistical analyses were conducted using IBM SPSS Statistics software, version 25 (IBM Corporation, Armonk, NY, USA). Results are presented as means and standard deviations.

Results

At baseline, the experimental and control groups were heterogeneous for accommodation facility ($P < 0.001$) and saccadic eye movement ($P < 0.001$), but homogenous for speed of recognition ($P = 0.836$), hand/eye coordination ($P = 0.562$), peripheral awareness ($P = 0.446$), and visual memory ($P = 0.729$). Paired t-test results indicate that for the experimental group for all measures, except visual memory ($P = 0.242$), statistically significant ($P < 0.05$) differences existed between the baseline and after-anaerobic treatment ($P < 0.001$ for all other measures). It therefore appears that the anaerobic treatment significantly influenced visual measures (Table 1).

In the control group, significant changes were found from baseline to re-test for accommodation facility (35.8 ± 4.6 to 38.0 ± 4.2; $P = 0.001$), saccadic eye movement (38.2 ± 6.9 to 40.6 ± 7.5; $P = 0.023$), peripheral awareness (65.4 ± 11.7 to 68.8 ± 7.8; $P = 0.045$), and visual memory (41.6 ± 5.1 to 43.4 ± 6.1; $P = 0.021$). This indicated that a learning effect did take place from baseline to re-test. No significant changes were observed for speed of recognition (28.8 ± 18.6 to 30.4 ± 20.1; $P = 0.200$), and hand/eye coordination (23.0 ± 5.3 to 23.6 ± 5.8; $P = 0.398$).

Independent t-tests found significant differences between the experimental and control groups at post-test for accommodation facility ($P < 0.001$), saccadic eye movement ($P < 0.001$), speed of recognition ($P = 0.036$), peripheral awareness ($P = 0.044$) and hand-eye coordination ($P = 0.042$), but not visual memory ($P = 0.729$). Further *post hoc* analysis using Hedges' correction effect size measure indicated a large effect size for accommodation facility ($g = -2.692$), saccadic eye movement ($g = -2.043$), speed of recognition ($g = -1.365$), hand/eye coordination ($g = -1.295$), peripheral awareness ($g = -2.457$), and confirmed only a small effect size between visual memory measures for baseline and after the anaerobic treatment ($g = -0.212$). For the control group, a medium effect size was found between measures for baseline and re-test with re-test providing a slightly higher mean score for accommodation facility ($g = -0.659$), saccadic eye movement ($g = -0.432$), peripheral awareness ($g = -0.377$), and visual memory ($g = -0.438$).

Discussion

This study used a new experimental approach to assess the effects of a maximal cycling all-out test on the performance of

Table 1. Effects of a maximal cycling all-out test on visual task performance.

	Experimental group (N = 30)				Control group (N = 30)				
Visual task parameter	Baseline	After 30-second Wingate anaerobic test	Within-group significance (P-value)	Effect size (g)	Baseline	Re-test	Within-group significance (P-value)	Effect size (g)	Between-group significance (P-value)
Accommodation Facility	15.7 ±2.3	18.7 ±2.6*	<0.001	−2.692	35.8 ±4.6	38.0 ±4.2*	0.001	−0.659	<0.001*
Saccadic Eye Movement	19.9 ±2.9	23.6 ±3.5*	<0.001	−2.043	38.2 ±6.9	40.6 ±7.5*	0.023	−0.432	<0.001*
Speed of Recognition	27.9 ±16.3	50.3 ±21.7*	<0.001	−1.365	28.8 ±18.6	30.4 ±20.1	0.200	−0.236	0.036*
Peripheral Awareness	22.3 ±4.1	26.5 ±3.9*	<0.001	−2.457	65.4 ±11.7	68.8 ±7.8*	0.045	−0.377	0.044*
Hand-Eye Coordination	63.6 ±4.6	73.2 ±4.6*	<0.001	−1.295	23.0 ±5.3	23.6 ±5.8	0.398	−0.155	0.042*
Visual Memory	41.0 ±8.0	42.5 ±6.2	0.242	−0.212	41.6 ±5.1	43.4 ±6.1*	0.021	−0.438	0.729

Data reported as means±standard deviations (SD). *: Statistical significance was set at $P \leq 0.05$.

several visual tasks. Results of this study indicate visual task performance increased in five of the six measured parameters, barring visual memory, following a 30-WAnT. While the control group too demonstrated improvements in visual task performance, such improvements were in four of the six measured visual task parameters, namely accommodation facility, saccadic eye movement, peripheral awareness, and visual memory, but not speed of recognition and hand/eye coordination. This may represent a rapid learning effect in these visual task tests. Despite the two groups being heterogenous for accommodation facility and saccadic eye movement, with the control group being significantly higher at baseline when compared to the experimental group, the control group still experienced a learning effect in these two parameters. As participants were randomised and not matched for any variables to avoid bias, this statistical heterogeneity for accommodation facility and saccadic eye movement became apparent only after the analysis of the results. Further, this heterogeneity represents clinical differences in the participants and does not represent a sampling error as all participants had no history of such visual task performance testing. While previous investigations on visual testing reproducibility have demonstrated that repeated processing might lead to training effects,[30–32] specific investigations regarding reproducibility are not forthcoming on the precise tests utilised in this study. To differentiate the learning effects from the exercise effects, this study demonstrated differences between the experimental and control groups at pre-test for five of the six visual task parameters, namely, accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness and hand-eye coordination, but not visual memory. This indicates that the exercise effect was significantly more than the learning effect on these parameters. Further, this study revealed only a medium effect size for learning effect on the measured parameter's compared to the large effect size for the exercise effect. As such, while the experimental group may have indeed also experienced some learning effect, the additional improvements in visual task performance could be attributed directly to the exercise effect.

Due to the novelty of this study, only the study of Fleury and Bard[8] supports the findings of this study when they found that anaerobic alactacid and anaerobic lactacid exercise improved sensory task (peripheral threshold detection), a sensory-motor task (coincidence-anticipation), and a cognitive task (recall in central vision) performance. What is particularly noteworthy is that both the present study and that of Fleury and Bard[8] differ from those studies that have examined the effect of prolonged aerobic exercise. In this regard, research has demonstrated artificial deleterious alterations in visual task performance following prolonged aerobic exercise. Specifically, maximal aerobic exercise has previously produced a limiting effect on cognitive function, impairing immediate memory composite scores, delayed memory composite scores, and verbal memory composite scores.[33] Connell et al.[34] too have demonstrated an impaired control of eye movement by examining ocular motor system function through saccadic eye movements following a strenuous cycling bout of prolonged exercise. In addition, Fery et al.[35] reported that cerebral hypoxia was seen to hamper central aspects of the visual system following prolonged cycling to exhaustion.

From previous studies, it can be seen that visual task performance may be artificially altered either negatively as following prolonged aerobic exercise or positively as following anaerobic exercise. This may be due to differences in central fatigue conditions following either prolonged aerobic exercise or short duration anaerobic exercise. In this regard, fatigue of the muscular system and resultant impairment of excitation-contraction coupling is proportional to the duration of the activity.[36] Muscular system fatigue leads to peripheral nervous system fatigue and eventually central nervous system fatigue. It is this central fatigue has been shown to produce vascular changes, hypoxia, decreased cerebral oxygenation, and cerebral cortical activity changes in the brain, which changes overall sensory inflow and alters central processing of afferent input, affecting visual task performance. However, it may be that short-duration exercise, albeit maximal, is not of sufficient duration to fatigue the muscular system sufficiently to result in central nervous system fatigue. In this regard, a study by Decorte et al.,[37] found that cycling to exhaustion led to peripheral fatigue that develops early during constant-load intense cycling, while central fatigue appeared to be present towards the end of the exercise after locomotor running.[38] It may be that that prolonged running, rather than cycling results in central fatigue and is more likely to result in a deleterious decline in the cognitive process affecting vision. This supposition is plausible due to movement related cortical potentials which validates that movement is preceded and accompanied by brain activities related to the preparation and execution of that movement.[39] This supposition is supported by previous research that indicates that visual function is affected by simultaneous physical and mental effort, so that a short-duration task, such as all-out maximal cycling has only minimal mental workload demands and may enhance visual and motor processing depending on the visual parameter tested, and those changes could be related to the activation state of the nervous system.[40]

In turn, these improvements following anaerobic training might be related to the fact that short-term maximal anaerobic exercise may result in positive excitatory and inhibitory muscle responses, not only at musculoskeletal level,[37] but also at central nervous system level. Although the mechanisms underlying these improvements in visual task performance have not yet been studied, it may be that short-term maximal anaerobic exercise provides "excitability" of the underlying motor cortex, "excitability" of the motoneurons utilised in visual task response and an enhanced "strength" of the mono- and oligosynaptic corticofugal connections.[37] Irrespective of the underlying mechanism, it appears that the sweeping improvements in visual task performance in this study following a maximal cycling all-out test provides appeal for the use of an intense, short-term warm-up when training visual skills or when visual skills form an integral part of athletic performance.

There were limitations to this research, including the lack of binocular testing, such as cover test, phorias, or vergences as part of the pre-study optometric assessment which could have led to some participants not being screened for conditions, such as strabismus or amblyopia, which could have a significant impact on accommodation, saccades, visual-motor integration, and visual perceptual skills. Further, due to the novelty of this research area, future studies should attempt to determine the duration or time-course effect of visual task improvement following different forms of exercise, such as high-intensity interval training (HIIT). This has obvious implications for sport where athletes presumably will benefit from even a minor improvement in visual skills during competition and where visual task assessments are used during sporting events (i.e. side-line assessments) to assess postinjury deficits.

Conclusion

These findings indicate that different physiological systems may determine visual performance under different exercise conditions. Also, different exercise conditions may affect some, but not all visual test measures. Hence, sport scientists need to consider all visual skills or tasks that an athlete must possess in their given sport and how that sport affect the said visual skills. This study may provide insight on the necessity of specific exercise modalities for use in warm-ups when training visual skills or when visual skills form an integral part of athletic performance. These findings will assist athletes, coaches, sport scientists and vision specialists to understand how exercise-induced fatigue or all-out exercise, and specifically the different types of metabolic fatigue, affects vision in their sporting discipline and enable the active development of strategies to take advantage of or mitigate the effect of all-out exercise on performance. The findings may have clinical relevance where side-line visual assessments are conducted at sporting events to assess postinjury deficits, such as to determine if an athlete has a concussion. These results highlight that if an athlete completes a vision test immediately following an injury/contact, there may be a need to understand the extent of any changes in visual function due to the acute exercise, potential injury, or a degree of both.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available from the corresponding author, Brandon S Shaw, upon reasonable request.

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