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Research Article

Effect of a Prolonged Maximal Bout of Exercise on Visual Performance

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Abstract

Background: Despite it being purported that acute, prolonged maximal periods of exercise may impair visual performance, little/no research on this topic is forthcoming. In fact, research has demonstrated that sub-maximal and maximal acute exercise may actually improve cognitive and sensory tasks and thus possibly improve visual performance.
Objectives: This study aimed to ascertain the influence of an acute, prolonged maximal bout of exercise on visual performance.
Methods: A quantitative study was undertaken with 60 untrained males being divided into a control group (CON; n = 30) or treatment group (TRE; n = 30). Both groups completed a baseline vision test battery consisting of accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness, visual memory, and hand-eye coordination using the following tests; Hart Near Far Rock, saccadic eye movement, evasion, accumulator, flash memory and Ball Wall Toss tests. Two weeks later, participants returned for follow-up testing using the same vision test battery, with the TRE participants first engaging in a standardized incremental maximal treadmill protocol immediately prior to their vision testing.
Results: Following the incremental maximal treadmill protocol, statistical analyses indicated that statistically significant ($P \leq 0.05$) differences existed for accommodation facility, saccadic eye movements, speed of recognition, hand-eye coordination, peripheral awareness, and visual memory between pre-test and after the aerobic treatment ($P = 0.00$ for all measures).
Conclusions: This study indicates that an acute, prolonged maximal bout of running improves visual performance. As such, an appropriate prolonged maximal warm-up may be required as opposed to a standardized and general warm-up when preparing an athlete for visual skills training or for participation in an athletic event that requires optimal visual performance.

Keywords: Aerobic Exercise, Exercise-Induced Fatigue, Metabolic Fatigue, Treadmill, Visual Fatigue, Visual Task

1. Background

The influence of a prolonged maximal bout of exercise on an individual's physical and/or cognitive performance has long been of interest to researchers in the fields of sports performance (1). Since movement is preceded and accompanied by brain activities related to the preparation and execution of movement, it is entirely plausible that exercise-induced fatigue can indeed deleteriously affect visual performance through central and or peripheral pathways. Problematically, different modes of exercise affect such pathways differently, with central fatigue more likely after prolonged running (ie, 30 kilometers) rather than cycling (2, 3). This may be so since 30 minutes of treadmill walking or running at speeds of 1.9 to 2.2 meters per second ($m.sec^{-1}$) (~ 6.84 - 7.92 kilometers per hour ($km.h^{-1}$)) may require more active control of attention (ie, for postural stability, control of vestibular and visual information centers (4) leading to more central fatigue.

In addition, exercise-induced fatigue is found to have a deleterious effect on physical performance leading to mental fatigue (5). The reverse of this relationship is also true in that mental fatigue has also been found to result in physical performance decreases (6). Further complicating this relationship are the detrimental effects of prolonged maximal exercise on cognitive functioning, resulting in mental fatigue (7) and potentially worsening visual performance. It is this effect of prolonged maximal exercise on central and peripheral pathways combined with mental fatigue that is purported to affect visual performance. Despite this supposition, only recently have laboratory studies begun to examine central fatigue in the oculomotor system following acute, prolonged exercise (8). In this regard, the limited findings available suggest that an acute, prolonged bout of submaximal exercise impairs saccadic velocity (8). However, it is still unknown how an acute, prolonged bout of exercise will impact the other newly identified visual skills important for athletic performance (9). This is because previous research has actually demonstrated improvements in sensory task (peripheral threshold detection), sensory-motor task (coincidence-anticipation), and cognitive task (recall in central vision) performance (10), all of which are critical in certain visual performances. Further, it is not known how an acute, prolonged bout of maximal exercise may affect vision since exercise has two main effects on the central nervous system (CNS), including not only inhibition, but also excitation. In this regard, it may be plausible that simple exercise modalities, such as running, create excitatory responses at a CNS level (11) that may actually stimulate the mechanisms underlying sports vision performance. As such, it remains to be determined whether an acute, prolonged bout of maximal exercise affects other components of vision or specific visual task performance. This study's findings would be the first, to the authors' knowledge, providing evidence of the stimulatory effects of an acute, prolonged bout of maximal running on visual performance. In addition, this study novelly explores the effect of an acute, prolonged bout of maximal running on six visual tasks, demonstrating a global visual effect.

Further, while previous research has demonstrated impaired saccadic velocity following submaximal exercise (8), the present study will determine the effect of maximal exercise on visual performance. This is important in that prolonged submaximal aerobic exercise is not the primary exercise modality for all or even the majority of sporting codes. As such, the findings of this study could assist conditioning specialists in understanding how different exercise modalities affect visual performance in their sporting discipline. This study hypothesized that an acute, prolonged bout of maximal running would improve visual performance.

2. Objectives

The objective of the study was to determine the influence of an acute, prolonged maximal bout of exercise on visual performance.

3. Methods

3.1. Participants

Sixty-one males (mean age: 23.11 $\pm$ 3.02 years) were recruited through local advertisements in or near the South African cities of Richards Bay and Kwadlangezwa using non-probability convenience sampling. Participants volunteered to participate in this study and were divided into a control group (CON; n = 30) or treatment group (TRE; n = 31). To be included in the study, participants were required to have a minimum of 20/20 vision, no visual disease or infection, physical disability, psychosocial distress, no participation in any form of structured exercise for the past six months, no previous experience with sports vision testing, no reading and/or speech impediment and/or no relative or absolute contraindication to exercise or testing (12-14). The participants gave informed consent subsequent to gaining information regarding the aims, data collection, and data management of the study. The University of Zululand's Institutional Review Board gave ethical approval for the study (UZREC 171110-030-PGD-2021/27). All procedures were conducted according to the Declaration of Helsinki for studies involving human participants.

3.2. Procedures

In this single-blind study, the same qualified sports scientist was responsible for data collection for all tests (Figure 1). All quantitative data were recorded manually by the investigator using existing, standardized protocols for Hart Near Far Rock Test, saccadic eye movement charts, and Ball Wall Toss. In turn, further quantitative data were recorded electronically for the standardized optometric assessment via the Spectrum Eyecare (Version 6.0.0 Digital Optometry, South Africa) and for speed of recognition, peripheral awareness, and visual memory via the Batak Pro (Quotronics Limited, Surrey, United Kingdom) software.

Participants underwent an optometric assessment to assess depth perception and visual acuity using Spectrum Eyecare software (Version 6.0.0 Digital Optometry, South Africa) to ensure 20/20 vision.

Once participants presented with 20/20 vision, six components of vision were measured using a visio-spatial intelligence (VSI) test battery; accommodation facility; saccadic eye movements; speed of recognition; hand-eye coordination; peripheral awareness, and visual memory (12). After two weeks, participants returned to undertake an incremental maximal treadmill protocol immediately followed by the same vision test battery.

3.2.1. Vision Test battery

This study made use of the Hart Near Far Rock Test to assess accommodation facility (15). While participants held the small Hart Chart at arm's length, the large Hart Chart was placed three meters away from the participants on a board, at head height (16). On the "go" signal, participants were required to recite the first letter of the first line of the large chart positioned 3 meters (m) away and then the first letter of the small chart an arm's length away, followed by the second letter, of the first line of the distant chart, then the second letter of the first line of the immediate chart and so forth for 30 seconds (sec). After 30 seconds, the mistakes were deducted from the score to define the ultimate score (16).

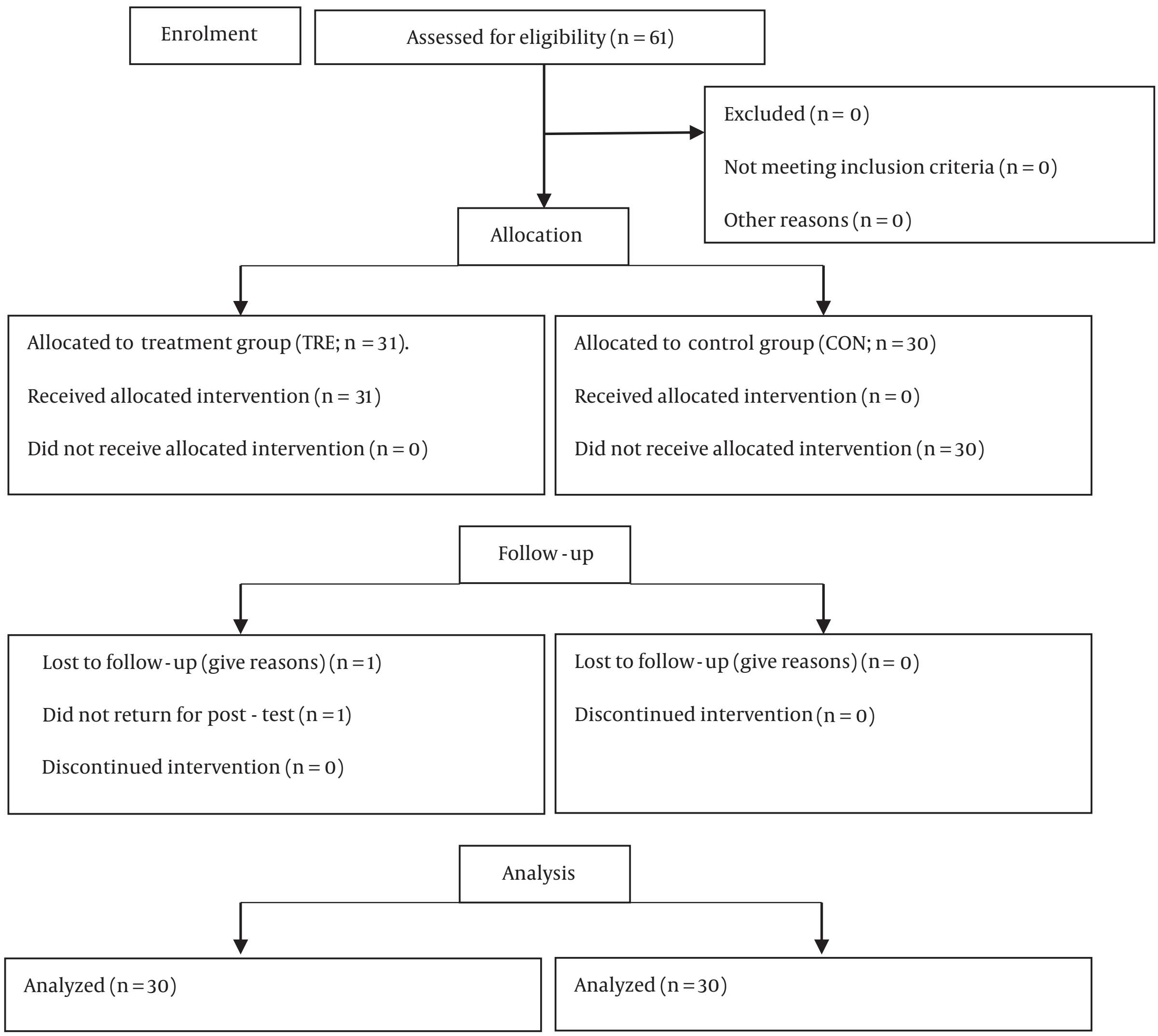

Figure 1. CONSORT flow diagram of study

Saccadic eye movement was assessed using saccadic eye movement charts (17). In this test, two charts were placed on a board, one meter apart and 3m away from the participants. To limit memorization, standardized, adjustable saccadic eye movement charts were utilized (16). On the "go" signal, participants recited the first letter on the lateral side of the left chart and then quickly recited the first letter on the lateral side of the right chart without moving their heads, followed by the second letter of the left chart and right chart and so forth for 30 sec. At the end of the 30 sec, mistakes were deducted from the score to define the ultimate score.

Speed of recognition was measured using the Batak Pro (Quotronics Limited, Surrey, United Kingdom) built-in Evasion Program (18). In this program, 12 light-emitting diode (LED) lights lit up randomly. Participants were required to touch each light if it remained constantly lit for 1 sec. However, if a light only flickered, participants were not to strike the target and if they did so, five points were deducted from the final score. Participants were required to evade the small central infrared beam when all of the lights in the middle of the Batak Pro flashed. If detected by the beam, five points were deducted from the final automatically determined score.

The Ball Wall Toss was utilized to assess hand-eye coordination (19). In this test, a target was marked on a wall two meters away from the participant. On the "go" signal, participants were required to throw and catch a standard tennis ball with alternating hands for 30 sec, and the number of successful catches was recorded as the final score (16).

Peripheral awareness was measured using the Batak Pro (Quotronics Limited, Surrey, United Kingdom) built-in Accumulator Program (20). This program causes random LED lights to become lit and remain so until touched by the participant. After being touched by the participant, another LED target would immediately light up for a period of 60 sec. The final score was calculated automatically by the Batak Pro microcomputer.

Visual memory was assessed using the Batak Pro (Quotronics Limited, Surrey, United Kingdom) built-in Flash Memory Program (21). For this program, six lights became lit for half a second. At the end of the sequence, participants were required to remember which six targets were illuminated, as well as the order in which they lit up. Scores were computed by the Batak Pro microcomputer.

3.3. Intervention

Following a two-week wash-out period after vision pre-tests, TRE participants returned to the laboratory and took part in a single bout of incremental maximal treadmill protocol (22). Since participants were sedentary, the present study made use of a protocol utilizing low initial speeds and small increments between stages (20) instead of protocols starting with high speeds and large increments between stages, such as the Bruce protocols. Participants were positioned on the treadmill (Johnson T8000 PRO treadmill, Johnson Health Tech. Co., Ltd, Taiwan) and initially walked at 2.0 kilometers per hour ($km.h^{-1}$) and 1% grade for 2 minutes. The protocol then increased to 5.5 $km.h^{-1}$ and 1% grade, with 0.2 $km.h^{-1}$ increments being added every 15 seconds. The grade was kept constant throughout until 16 $km.h^{-1}$ was reached, at which point grade increments increased by 0.5% every 30 sec. Participants then immediately took part in the same vision test battery as at pre-test. To determine if a learning effect occurred across the experimental period, CON participants returned and undertook the same vision test battery without performing the incremental maximal treadmill protocol immediately beforehand.

3.4. Statistical Analysis

SPSS Statistics software, version 25, was utilized in the statistical analyses (IBM Corporation, Armonk, NY, USA). The results are presented as means and standard deviations. Data analysis involved the determination of normality of data using the Shapiro-Wilk test and dependent and independent *t*-tests to determine if any changes occurred both within and between groups, respectively. Post hoc analysis of effect size was determined using Hedges' correction, with effect sizes of 0.2 to 0.5 being a small effect size, 0.5 to 0.8 being a medium effect size, and effect sizes equal to and larger than 0.8 being considered a large effect size. A probability of $P \leq 0.05$ was set for the study.

4. Results

Of the 31 participants enrolled in the TRE, one participant was excluded from the study as a result of a failure to attend the post-test. At pre-test, the CON were found to be homogenous for accommodation facility (P = 0.94) and saccadic eye movement (P = 0.23), for speed of recognition (P = 0.10), hand/eye coordination (P = 0.26), and visual memory (P = 0.66), but heterogeneous peripheral awareness (P = 0.00). In turn, the TRE were heterogeneous for accommodation facility (P = 0.00) and saccadic eye movement (P = 0.00) but homogenous for speed of recognition (P = 0.84), hand/eye coordination (P = 0.56), peripheral awareness (P = 0.45), and visual memory (P = 0.73).

Following the incremental maximal treadmill protocol, statistical analyses indicated that statistically significant ($P \leq 0.05$) differences existed for all vision measures between the pre-test and after the prolonged maximal bout of exercise (P = 0.00 for all vision measures) (Table 1). It therefore seems if the prolonged maximal bout of exercise significantly influenced all visual performance measures.

Table 1. Effects of a Prolonged Maximal Bout of Exercise on Visual Performance [a]

	Pre-test (N = 30)	Post-test (N = 30) [b]
Accommodation facility	15.65 ± 2.26	19.61 ± 3.02 [c]
Saccadic eye movement	19.90 ± 2.93	24.48 ± 3.75 [c]
Speed of recognition	27.87 ± 16.31	54.94 ± 18.57 [c]
Peripheral awareness	22.26 ± 4.10	26.32 ± 3.46 [c]
Hand-eye coordination	63.61 ± 4.55	74.13 ± 5.43 [c]
Visual memory	40.97 ± 7.99	41.65 ± 5.82 [c]

[a] Data reported as second (mean ± SD).
[b] Post-test: Following an incremental maximal bout of exercise protocol.
[c] Probability was set at $P \leq 0.05$.

For the CON, significant changes were found from pre- to post-test for accommodation facility (35.80 ± 4.57 to 38.00 ± 4.24 sec; P = 0.00), saccadic eye movement (38.20 ± 6.92 to 40.63 ± 7.45 sec; P = 0.02), peripheral awareness (65.37 ± 11.65 to 68.80 ± 7.80 sec; P = 0.05), and visual memory (41.57 ± 5.10 to 43.40 ± 6.10 sec; P = 0.02). No significant changes were observed for speed of recognition (28.80 ± 18.56 to 30.37 ± 20.06 sec; P = 0.20), and hand/eye coordination (22.97 ± 5.33 to 23.63 ± 5.75 sec; P = 0.40).

Post hoc analysis revealed a large effect size between pre- and post-test measures; accommodation facility (g =

2.25), saccadic eye movement (g = 1.90), speed of recognition (g = 1.72), hand/eye coordination (g = 1.53), and peripheral awareness (g = 2.43). However, only a small effect size was found between measures for pre-test and after the prolonged maximal bout of exercise for visual memory (g = 0.09). Conversely, only a medium effect size was found between measures for pre- and post-test for the CON for accommodation facility (g = 0.66), saccadic eye movement (g = 0.43), peripheral awareness (g = 0.38), and visual memory (g = 0.44).

5. Discussion

The main aim of this study was to determine the influence of an acute, prolonged maximal bout of exercise on visual performance. This study found that accommodation facility, saccadic eye movements, speed of recognition, hand-eye coordination, peripheral awareness, and visual memory improved following a single bout of incremental maximal treadmill running.

Contrary to this study, previous research has found that progressive treadmill exercise that recruited glycogen and oxygen does not affect a visual detection task (23). However, it must be noted that the study of Fleury et al. (23) utilized a physically fit population, whereas the present study utilized sedentary participants. Also, previous research has demonstrated that a submaximal cycle test (at 75% of maximal work capacity (Wmax)) improved simple cognitive tasks important for visio-spatial intelligence (VSI), such as simple reaction time and even complex measures of working memory and attention (24). Previous research has demonstrated that 180 min of stationary cycling at a work rate equivalent to 60% of maximal aerobic capacity impairs a single visual task, namely saccade velocity (8). When compared to this study, the contrary findings could be due to the use of a submaximal intensity being insufficient to result in excitation of the CNS. This is especially true since a submaximal effort may especially be insufficient to excite the CNS in their well-trained cyclists (VO_{2max}: 57 $\pm$ 1 mL.kg.min^{-1}). Further, in addition to intensity, the long duration of cycling in the study of Connell et al. (8) may have been more suited to central fatigue, and it may be that a time-course exists between prolonged exercise and visual performance, as it does with cognitive function (25). This is because prolonged exhaustive exercise may be more efficient at inducing hypoglycemia and muscular glycogen depletion (26) than the current study's shorter, albeit maximal, exercise bout.

While the mechanisms explaining how an acute, prolonged maximal bout of treadmill running can improve visual skills are yet to be explored, a substantial amount of research has investigated the effects of acute exercise on cognitive function (27). Some of these findings may also explain the acute improvements in visual performance following acute exercise. In this regard, acute exercise has been found to have a generally positive effect on cognitive functioning, especially in areas of prefrontal cortex-dependent cognition (28). This may too be the case in improving visual performance since frontal brain areas are also now identified in generating the contents of visual perception. Specifically, the frontal cortical area, the frontal-eye field (FEF), has been shown to have fast visual responses (29). In addition, acute exercise has been demonstrated to have a positive influence on time trial performance, exercise capacity (time to exhaustion), and subjective effort. This is because of acute exercise central or brain catecholamines, which increase arousal by activating the reticular formation in what is termed the "catecholamines hypothesis" (30). In addition to catecholamines, other neurochemicals, such as hypothalamic-pituitary-adrenal cortex (HPA) axis hormones and brain-derived neurotrophic factor (BDNF) may also play a role in arousal and possible improvements in visual performance following acute, prolonged maximal exercise (30).

In addition, while stimulating as well as detrimental effects of exercise on cognitive functioning have previously been reported, and such effects may also exist on visual performance, fatigue effects may be task-specific (1). In this regard, it may be that this study's prolonged maximal bout of treadmill running may not sufficiently simulate training and/or competition conditions, which requires the exertion of cognitive control, which in turn, may result in appropriate mental, combined with physical, fatigue that negatively impacts visual performance. This is because sport requires active control of attention for visual tasks resulting in not only physical, but also simultaneous mental fatigue (31). In addition, treadmill running may not sufficiently simulate the field-based sports fatigue that is purported to affect visual task performance.

The importance of these findings is that they indicate that sport scientists need to consider all visual skills or tasks that an athlete must possess in their given sport and how the bioenergetics of that sport affects the said visual skills. Rather than simply continuing to accept that exercise-induced fatigue is inherently negative to performance, these findings challenge sport scientists' beliefs regarding fatigue's role in athletic performance. These findings will assist athletes and conditioning specialists in understanding how different all-out physical efforts from the various physiological energy pathways may affect vision in their sporting discipline. Our study had several strengths, one of which was the use of experimental evidence to determine that an acute, prolonged maximal bout of treadmill running actually improves visual performance. Additionally, this study made use of an independent control group and not a crossover design to avoid nonconstant variances for all observations and to account for the possibility of carryover effects or bias from the previous treatment (32). In addition, this study did not only assess a single visual skill, but rather six different visual skills (ie, accommodation facility, saccadic eye movement, speed of recognition, peripheral awareness, visual memory, and hand-eye coordination) in determining if visual improvements were a global phenomenon or finding, rather than an isolated or haphazard effect. This study also utilized sedentary participants in order to avoid the training effects or adaptations that could have been present and that could have affected performance and recovery from the acute, prolonged maximal bout of treadmill running.

5.1. Limitations

The sample of the study was not systematically drawn and utilized a male-only sample since females have central limitations in oxygen delivery when compared to males (33), which could have affected exercise responses. This study also utilized untrained participants, and it is plausible that trained participants may respond differently to a prolonged maximal bout of exercise (23). It is also important to note that this study only utilized six visual skills based across a broad spectrum. However, a multitude of visual skills exist and are being discovered (34) that may have been affected by a prolonged maximal bout of treadmill running. In addition, this study did not compare all out (maximal) prolonged exercise with submaximal aerobic exercise. This study also did not compare the effect of different modalities of prolonged maximal exercise (ie, cycling vs running) since each make use of different pathways to influence central fatigue (2, 3), and thus may affect visual performance differently. However, it was proposed that prolonged maximal exercise would most likely affect visual performance due to running requiring more active control of attention (ie, for postural stability, control of vestibular and visual information centers (4)) leading to more central fatigue, and thus have more of an effect on visual performance than cycling.

5.2. Conclusions

This study indicates that a prolonged maximal bout of exercise improves visual performance. As such, an appropriate prolonged maximal warm-up may be required as opposed to a standardized and general warm-up when preparing an athlete for visual skills training or for participation in an athletic event that requires optimal visual performance.

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Footnotes

Authors' Contribution: Brandon S. Shaw initiated and planned the study, data gathering, statistical analyses, and writing of the article; Gerrit Breukelman contributed with data gathering and constructing the paper; Lourens Millard contributed with data gathering and constructing the paper; Ina Shaw assisted with initiation and planning of the study, statistical analysis and writing the paper. The authors have reviewed the ultimate version of the article; and agree to take responsibility for all components of the study.

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Informed Consent: Prior to participation in the study, all participants gave their written informed consent.

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