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Do generalized visual training programmes for sport really work? An experimental investigation

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We assessed the effectiveness of two generalized visual training programmes in enhancing visual and motor performance for racquet sports. Forty young participants were assigned equally to groups undertaking visual training using Revien and Gabor's *Sports Vision* programme (Group 1), visual training using Revien's *Eyerobics* (Group 2), a placebo condition involving reading (Group 3) and a control condition involving physical practice only (Group 4). Measures of basic visual function and of sport-specific motor performance were obtained from all participants before and immediately after a 4-week training period. Significant pre- to post-training differences were evident on some of the measures; however, these were not group-dependent. Contrary to the claims made by proponents of generalized visual training, we found no evidence that the visual training programmes led to improvements in either vision or motor performance above and beyond those resulting simply from test familiarity.

Keywords: perception, racquet sports, training, vision.

Introduction

Sports coaches, performers and scientists are constantly in search of new means to enhance sports performance and gain a competitive advantage. With diminishing returns in performance gains likely through traditional sport science sub-disciplines such as physiology, biomechanics and psychology, there has been increasing interest over the past few decades in the potential contributions of other fields and professions. Particularly active over the past decade have been sports optometrists, who have extended their traditional role in routine visual screening, testing and lens prescription for athletes to the administration of various forms of vision therapy or visual training designed to improve sports performance. The visual training programmes offered by optometrists have strong commercial support, are marketed with vigour and enthusiasm, are claimed to be extremely effective and are being increasingly used by a large range of athletes. The question we sought to examine experimentally in this study was whether such programmes really work (in improving both the vision and performance of athletes) or whether the claims for their efficacy in improving sports performance are unfounded.

Most visual training programmes currently used by sports optometrists are generalized programmes adapted directly from pre-existing programmes used in clinical optometry to improve the vision of children, particularly those experiencing reading difficulties. These programmes use repetitive eye exercises (typically to generic alphanumeric stimuli) to try to improve basic visual functions (such as acuity, eye tracking and depth perception) and, through this, sports performance. Despite their growing use, and the strong claims made by proponents of visual training regarding their effectiveness, the evidence to demonstrate that such programmes can improve both vision in general, and sports performance in particular, is almost entirely anecdotal and, consequently, subject to bias and expectancy effects. Several critiques of the sports vision literature, both by sports optometrists (e.g. Stine *et al.*, 1982; Hazel, 1995) and sport scientists (e.g. Abernethy, 1986; Landers, 1988; Herman and Retish, 1989),

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have commented on the lack of appropriate empirical evidence upon which to evaluate the claims made in favour of different visual training programmes.

The effectiveness of generalized visual training programmes rests upon three key assumptions: that vision is directly related to sports performance (such that sub-normal vision is detrimental to sports performance and that supra-normal vision is beneficial to sports performance); that key visual attributes for sport can be trained; and that improved vision translates to improved sports performance. If one of these assumptions is false, then visual training programmes, of the generalized type currently prescribed, will not benefit sports performance, at least not through the putative mechanism of enhancing the visual skills prerequisite to expert performance. Relevant research exists to examine the truth of some but not all of these assumptions.

If the first assumption underpinning visual training is true, then it would be reasonable to expect elite athletes to be characterized by better basic visual function and less skilled performers by a greater prevalence of visual defects and poorer visual function. Whether or not this is true depends upon how visual skills are defined and, most importantly, measured. Contrary to the basic assumption, elite athletes are frequently reported to have a surprisingly high incidence of uncorrected visual defects (e.g. Garner, 1977) suggesting that below-average vision may not necessarily be inconsistent with superior sports performance. This conclusion is supported by recent evidence from studies on basketball free-throw shooting, which demonstrated that even a visual characteristic as apparently fundamental as visual acuity can be degraded quite dramatically (through the progressive introduction of blurring) without having any major impact on motor performance (Applegate and Applegate, 1992). Below-normal vision may not be as detrimental to sports performance as has traditionally been thought.

In a similar vein, the weight of available evidence argues against supra-normal basic visual function being necessary for elite sports performance, as expert performers do not appear to self-select on the basis of superior visual function. Despite some early support for basic eye factors that may discriminate elite from less skilled athletes (e.g. Graybiel *et al.*, 1955; Williams and Thirer, 1975), increasingly the consensus is that expert and novice athletes are not characterized by differences in basic visual function (Starkes and Deakin, 1984; Abernethy, 1987). Rather, the expert's advantage appears to be perceptual, related not to basic visual function but to how domain-specific visual information is interpreted and used to guide action.

Evidence exists for strong and systematic differences between experts and novices on sport-specific measures of pattern recognition (e.g. Allard *et al.*, 1980) and anticipation (e.g. Abernethy and Russell, 1987), which persist when basic visual function is indistinguishable between the different skill groups (Starkes, 1987; Helsen and Pauwels, 1993; Abernethy *et al.*, 1994). In studies that have reported some significant expert advantage on one or more general visual function measures, such differences typically accounted for only a very small portion of performance variance (e.g. Hughes *et al.*, 1993). Collectively, the existing evidence argues against the assumption of a direct relationship between measures of basic visual function and sports performance and, consequently, suggests that improving basic visual function is unlikely to lead automatically to superior sports performance.

The second assumption that underpins the use of generalized visual training programmes for sport is that attributes of basic visual function can be trained. There is now quite convincing evidence to demonstrate that most commonly measured visual functions can be improved through training. Functions that have been shown to improve with repetitive practice include foveal and peripheral stereoacuity (Fendick and Westheimer, 1983), foveal vernier acuity (McKee and Westheimer, 1978), dynamic (Long and Rourke, 1989) and peripheral visual acuity (Saugstad and Lie, 1964), contrast sensitivity for diagonal gratings (Mayer, 1983), accommodation (Rouse, 1987), vergence (Daum, 1982), peripheral motion thresholds (Johnson and Leibowitz, 1974) and visual field size (Wood *et al.*, 1987). However, it is not yet clear what type, frequency and distribution of training is best for optimizing the rate of functional improvement in each of these particular visual characteristics.

Despite the clear-cut evidence for the training of basic visual attributes, some caution needs to be exercised when extrapolating this evidence to the use of visual training in athletes. One reason for this caution is that many of the reported improvements with visual training have been in patients with visual defects (American Optometric Association, 1988). Because of possible ceilings for general visual improvement, it does not necessarily follow that comparable improvements can or will occur for people entering a visual training programme with normal or above-normal visual function. A second reason for caution is that, in many instances, the exercises used to *train* vision are identical to, or simple variants of, the procedures used to *test* basic visual function. As a result, it is frequently difficult to ascertain whether pre- to post-training improvements in basic visual function are a consequence of a genuine improvement in visual function or merely the effect of extended practice on the test instrument. Although the general evidence on the efficacy of improving basic visual function through repetitive practice is promising, there is no specific evidence at present to conclude unequivocally that visual training programmes applied to athletes will necessarily enhance general visual performance in the same way as reported in the clinical literature.

The third, largely untested, assumption that underpins generalized visual training programmes for athletes is that any improvements in basic vision achieved through training will transfer automatically to improved sports performance. The assumption of a causal linkage between basic visual function and sports performance is at the very heart of the issue of the probable effectiveness of generalized visual training. While, as a first approximation, the assumption of a direct transfer of improved visual function to improved sports performance may seem a logical and reasonable one, closer scrutiny would suggest that this need not be the case. It is possible to envisage scenarios in which general visual function may improve but need not affect sports performance. Such scenarios could arise, for example, if general visual function is not the limiting factor to sports performance or if the essential coupling between improved vision and movement production has not occurred. Conversely, it is possible to envisage many circumstances in which sports performance may improve without concomitant changes in general visual function (for example, through improved confidence, technique modification or improvements in the knowledge base underpinning perception).

In assessing the evidence for the efficacy of visual training nearly 20 years ago, Stine *et al.* (1982, p. 633) noted: 'That visual training enhances the athlete's ability to perform has not been conclusively demonstrated . . . there are no valid, controlled studies that prove a positive relationship between visual training and athletic performance, nor are there any studies that disprove a relationship'. Since that time, only a few additional controlled studies on the effectiveness of visual training exercises have been reported. Harper *et al.* (1985) compared the visual and motor performance of groups of rifle and pistol shooters after 2 weeks of visual training. They found no significant differences in the visual parameters of dynamic visual acuity, depth perception and peripheral awareness or in shooting performance between a group who experienced visual training and a control group who were given relaxation training. Vedelli (1986) compared the coincidence-timing performance of 12 individuals given 6 weeks of visual training – using the eye exercises prescribed by Revien and Gabor (1981) with three 15-min practice sessions per week – with a control group of equal size given no such training. A significant improvement in hitting a tennis ball for accuracy was found in favour of the experimental group, but the design did not permit exclusion of possible Hawthorne effects or include checks to ensure that attributes of visual function had actually been improved by the training. In a series of studies comparing performance on selected motor tasks by groups given training using Revien's (1987) *Eyerobics* visual training programme and a control group given no training, McLeod and co-workers have claimed support for the benefits of visual training in improving static balance and hand–eye coordination as assessed using manual tracking (McLeod and Hansen, 1989a,b; McLeod, 1991). However, as Cohn and Chaplik (1991) have pointed out, this evidence is weak *inter alia* because of the lack of suitable placebo controls. Similarly, a recent study by West and Bressan (1996) showed some benefits of a generalized visual training programme on judgement of ball flight by cricket batsmen, but these benefits occurred in the absence of significant improvements on all but one of the visual skills measured. This points strongly to the possibility of performance benefits arising through mechanisms other than improved basic visual function and again highlights the need to include a suitable placebo group.

In a more recent study, which included a placebo group as well as a standard control group, Wood and Abernethy (1997) found no evidence of improved visual or motor performance in a group receiving 4 weeks of visual training using exercises of the type typically used by sports optometrists (e.g. see Coffey and Reichow, 1995). These visual training exercises typically involve greater use of direct optometrist supervision in the training process than the self-help exercises of the type contained in *Eyerobics* and related commercial packages. Of central interest in the present study was to replicate the study by Wood and Abernethy (1997) using commercially available visual training packages, particularly those that have formed the basis of previous, unresolved debate in the literature (cf. Cohn and Chaplik, 1991; McLeod, 1991).

The aim of this study was to determine if 'self-help' visual training programmes that are commercially available can enhance visual performance and, in turn, performance on a sport task. The visual and motor performance of people trained using the eye exercises for athletes described by Revien and Gabor (1981) (Group 1) and the video-based *Eyerobics* training tape of Revien (1987) (Group 2) was compared with that of participants given reading materials on the sport of tennis, designed to enhance their confidence and expectation of success (Group 3), and those given no systematic visual training (Group 4). The visual training programmes of Revien and Gabor (1981) and Revien (1987) were selected not only because they are representative of the commercial prescriptive self-help programmes readily available to athletes and coaches, but they have also been the subject of previous study and both make strong claims about their effectiveness in enhancing sports performance.

Revien and Gabor (1981, p. 21) claimed that 'visual training . . . may well make the difference between winning and losing, between revelling in keen competition or shrinking from it'. Similarly, Revien (1987, p. 5) made the claim that the training exercises contained on the *Eyerobics* tape will improve: visual skills; mental and physical performance; ability, speed and accuracy to recognize over a larger area; awareness and perception of all objects in space; and concentration and confidence. If the claims are valid, then the two experimental groups should perform better than the placebo and control groups on both visual parameters and motor performance by the end of the training programme. In contrast, the prediction based on evaluation of the assumptions underlying visual training, on the general arguments raised against vision therapy by ophthalmologists (e.g. Heiger, 1984) and on the empirical evidence of Wood and Abernethy (1997), is that even if the programmes succeed in enhancing basic visual function, this is unlikely to transfer into a motor performance advantage for the experimental groups over the other groups. Superior motor performance by either or both of the visual training groups, achieved in the absence of improved basic visual function, will be taken as evidence of placebo effects.

Methods

Participants

The participants were selected from a pool of male and female university undergraduates aged 16–28 years who had no specific competitive experience in racquet sports. All were pre-screened for visual defects and ocular disease; individuals who normally wear prescription lenses to play sport were tested while wearing these corrections. Pre-screening included an assessment of fixation disparity/binocular stability, screening for red–green colour defects and an ophthalmoscopic inspection by a trained clinical optometrist. Individuals with uncorrected refractive errors or ocular disease were omitted from the study. This action was taken because visual training programmes are typically advocated for use in enhancing visual performance beyond normal and as an addition to, rather than as a substitute for, the use of prescription lenses in alleviating visual defects.

After an initial screening of about 60 individuals, 40 aged 16–28 years (mean 18.9 years) were invited to participate in the experiment. These participants were allocated in a quasi-random fashion to form four equal groups. The allocation of individuals ensured that each group contained equal numbers of males and females. An attempt was also made to ensure that those participants scoring above and below average on basic visual and motor test measures were evenly distributed across the four groups. Participation was on a voluntary basis and the participants were free to withdraw from the study at any stage.

Experimental design

The experimental design was essentially identical to that used by Wood and Abernethy (1997), with the exception of two visual training groups rather than one (see Fig. 1). The two experimental groups (Groups 1 and 2) each undertook different types of visual training. The members of Group 1 were trained using exercises from Revien and Gabor's (1981) *Sports Vision* programme of eye exercises for athletes, while the members of Group 2 were trained using the *Eyerobics* videotape-based training programme (Revien, 1987). Each visual training group undertook four 20-min visual training sessions and one 20-min motor practice session per week for 4 weeks. All training sessions were supervised. The motor practice session was spent on the criterion sport task of hitting tennis forehand drives for accuracy. The total visual training provided exceeded the time period and frequency of practice claimed by proponents of visual training (Revien and Gabor, 1981) to be sufficient to improve sports performance.

Group 3 (the reading group) attended the same amount of supervised training each week as the two visual training groups, spending four 20-min sessions per week reading about and watching televised tennis matches and one 20-min session per week undertaking motor practice. Both visual training groups and the reading group were given preliminary statements about the expected positive effects on sports performance of the training they were undertaking. The purpose of this instruction was to give participants in Groups 1–3 comparable amounts of both supervised attention and expectation of benefits from their respective training regimens. Group 4, the control group, received no visual or supervised training of any form throughout the 4 weeks of practice; all they undertook was one 20-min motor practice session per week. Participants in the control group were given no *a priori* statements about the expected effects or benefits of the practice they were undertaking.

At the end of the 4 weeks practice, all participants were re-tested on the same visual and motor parameters tested before training; the differences on each of the parameters were then compared between groups. Comparison of changes in visual and motor performance over the practice period for the visual training

Pre-test	Group allocations	Training period				Post-test
		Week 1	Week 2	Week 3	Week 4	
Pre-test on all visual and motor parameters resulting in allocation of participants to groups	Visual training groups (Groups 1 and 2)	4 x 20-min visual training sessions + 1 x 20-min motor practice session	as per week 1	as per week 1	as per week 1	Post-test on all visual and motor parameters
	Reading/placebo group (Group 3)	4 x 20-min reading and television sessions + 1 x 20-min motor practice session	as per week 1	as per week 1	as per week 1	
	Control group (Group 4)	1 x 20-min motor practice session only	as per week 1	as per week 1	as per week 1	

Fig. 1. The experimental design of the study.

groups and the reading group allowed us to determine the effects of visual training as opposed to placebo or Hawthorne effects. Comparison of pre- to post-training changes in visual performance for the visual training and reading groups with the control group provided an indication of the extent to which any such changes were due simply to familiarity with the test procedures, as opposed to genuine improvements owing to the specific training undertaken. All groups had motor practice weekly, providing all participants – but the visual training group in particular – with the opportunity to match progressively or (re)calibrate any alterations in the functioning of their visual system with the requirements of the motor system (Smyth and Marriott, 1982). This was important given the essential functional interdependences between perception and action (Turvey and Carello, 1986).

Training procedures

Group 1. Participants in this group undertook visual training using the eye exercises described by Revien and Gabor (1981, pp. 28–111), with the exercises administered in the order and for the duration suggested in their sample training programme (pp. 24–25). Each of the exercises was repeated, but with progressively increased task difficulty, in weeks 2, 3 and 4 of the training programme. The exercises were implemented following precisely the procedural instructions provided in the *Sports Vision* training manual. The specific exercises included in the training programme were as follows:

1. *Light stimulation exercise.* A hand-held flashlight was used to cast rapid alternating sequences of light and dark on the retina in an attempt to stimulate and improve the sensitivity of central retinal receptors and, through this, visual acuity.
2. *Spiral rotation exercise.* An attempt was made to train the temporary illusion of enlarged object size, which occurs immediately subsequent to prolonged viewing of a rotating spiral. The assumption behind the use of this exercise is that, having experienced object enlargement, albeit temporarily, through this illusion, athletes may then be able to voluntarily induce the appearance of greater object size (and hence presumably enhance acuity) whenever it is required.
3. *Chord ball training.* This exercise involves training on a modified version of the Brock string and purports to improve accommodation and convergence skills. Participants are required to make rapid fixational shifts among target beads located at different distances along a taut length (~ 3 m) of chord. The rapid changes in fixation point induce physiological diplopia, which is utilized phenomenologically in the instructions given on the task.
4. *The swinging ball exercise.* This involves participants visually tracking (without head movements) a ball moving across the field of view. The rationale behind this exercise is that training the eyes to move in a smooth, coordinated fashion will improve timing and efficiency, as well as making the athlete less prone to distraction.
5. *Swinging ball with pointed finger.* This is a simple variant of the previous one, the only exception being that the motion of the ball is this time also tracked with the hand in an attempt to improve hand–eye coordination.

6. *Coloured rotor exercise*. The principal stimulus device for this exercise is a disk containing a distinguishable black dot among shapes and sizes of different colours. The disk is rotated at different speeds and the task is to track binocularly the black dot using smooth eye movements. The exercise aims to improve peripheral awareness, the rationale being that the 'bright background with shapes in various colours, and the constant movement, all serve to stimulate the retina, increasing its sensitivity and enabling you to discern more, and better, in the peripheral range of vision' (Revien and Gabor, 1981, p. 76).

7. *Marbles in a carton exercise*. A medium-sized cardboard box containing 6–12 marbles of different colours, within which is marked a central black dot, is used for this exercise, which Revien and Gabor (1981) claim enhances peripheral awareness. The participant's task, like that in the previous exercise, is to focus on the central black dot while tipping the box to create random motion of the marbles across different parts of the visual field.

8. *Flip-card practice*. This involves using 50–100 marked index cards to produce a manual form of the typical tachistoscopically presented memory span test. Cards are marked with a central fixation dot and two 2-digit stimuli positioned equidistant but progressively displacing from the central fixation point. The task is to identify both sets of numbers as the card set is rapidly flipped through the fingers. Revien and Gabor (1981) claim that repetitive practice will not only improve speed and span of recognition, but also peripheral visual range.

9. *String pull exercise*. This exercise, which aims to enhance depth perception, is essentially a modification of the Howard-Dolman method used to test depth perception. A long (~ 8 m) piece of string is hooked through two eyelets screwed to a solid object approximately 4 m from the participant and configured so that the participant is able to hold one end of the string in each hand. The task is then to align the single beads on each piece of string so that they are positioned equidistant.

Warm-up and warm-down exercises, as suggested by Revien and Gabor (1981, pp. 28–35 and 96–105), were also incorporated into each visual training session. The one 20-min session of motor practice per week undertaken by all participants in Group 1 consisted of continuous practice on the criterion motor task of stationary and moving tennis forehand drives for accuracy.

Group 2. In addition to the 20 min of motor practice per week experienced by all other groups, Group 2 undertook four 20-min sessions per week of visual training using exercises taken directly from Revien's (1987) *Eyerobics* video package. The *Eyerobics* package consists of the following six training exercises:

1. *Rotating spiral exercise*. Essentially, this is a videotape version of the spiral rotation exercise undertaken by the participants in Group 1. The author claims the exercise 'improves circulation and retinal stimulation and visual acuity' and 'creates a beneficial visualization stored in the brain and used when concentrating'.

2. *Rotating target exercise*. The participants were instructed to follow, with both eyes, the circular movement of a target (a ball) on screen while maintaining a fixed head position. The difficulty of the task was progressively increased by adding distracting stimuli and background colour changes and by increasing the distance between the viewer and the monitor from 1 to 2 m. This exercise purports to 'improve eye coordination, concentration, binocular control and pursuit reflexes'.

3. *Grid tracing exercise*. This exercise requires the participants to detect as quickly as possible, and follow as closely as possible, the motion of a dot as it traverses a grid network. Task difficulty is incremented by having the target dot move faster and make more frequent changes in direction. The claimed benefit of this exercise is the improved ability to 'quickly recognize, focus on and follow a moving object in any direction'.

4. *Speed and span of recognition exercise*. Like the flip-card exercise undertaken by participants in Group 1, this exercise tries to enhance speed and span of recognition (and faster reaction to objects over a large area) by having participants mentally repeat a number sequence or select the end number in a large sequence when the sequence is only presented for a very brief period of time (< 100 ms). Task difficulty was progressed not only by decreasing the exposure duration for the stimuli, but also by increasing the length of the stimulus sequence, by adding background distractors, and by varying the location and physical size of the stimulus sequences.

5. *Barber pole exercise*. This involves an image of a barber's pole rotating continuously through different spatial locations with the speed and frequency of directional changes in the rotation of the pole being progressively increased. Participants were instructed to alternate concentration from the top to the bottom of the rotating pole while maintaining a fixed head position. The exercise purports to 'increase the appreciation and awareness of objects in space' and 'improve mental spatial orientation and binocular coordination'.

6. *Rotation 3D exercise*. For this section of the training programme, the participants were required to view the screen through glasses containing red/green filters. Static images of stylized sports figures were presented which rotated in three dimensions and which, with the appropriate lenses, created the illusion of changing

depth. The author claims this viewing exercise 'improves depth perception in all areas' and 'creates smooth effortless motion of both eyes together'.

All of the training sessions of Group 2 were supervised. The training schedules developed used progressions within each of the exercises consistent with the training schedules provided with the manual accompanying the videotape. The difficulty of the exercises was increased progressively over each of the 4 weeks of training.

Group 3. The participants in Group 3 attended as many sessions (4 × 20 min) and experienced as much motor practice (1 × 20-min session) per week as those in the other groups. The members of group 3 spent two of their 20-min sessions reading instruction books on playing tennis and the other two sessions watching videotape replays of matches from the 1990 US Open tennis tournament. Participants in this group were given a statement at the outset of the training period about the expected positive effect of sports knowledge on sports performance. This statement was made in an attempt to match the expectations established by the statements contained in the visual training materials presented to Groups 1 and 2, thus providing an effective placebo control group.

Group 4. The participants in this group only undertook the weekly 20-min practice on the motor task. The principal purpose of this group was to provide baselines in improvement on the motor performance task and to ascertain the extent of any pre- to post-training improvements in visual performance that were simply a function of test familiarity.

Tests of visual function and motor performance

The visual and motor tests served several functions in this study: further screening of participants for uncorrected visual defects and ocular disease; allocation of individuals to groups; and, most importantly, assessment of the relative pre- to post-training differences in performance. To fulfil these functions adequately, it was essential that a set of tests was assembled that was sufficiently sensitive to detect any changes in visuomotor performance. The tests also need to be appropriate to the parameters of visual performance that the specific visual training exercises purport to improve, and representative of typical test batteries used for the general assessment of visual and motor performance. Moreover, it was important that the tests used assessed the same general visual skills that the visual training programmes purport to improve but that they used assessment procedures that were not identical to those used in any of the training exercises. The following general visuo-perceptual tests and sport-specific motor tests were selected for use in this project. The general visual function tests were derived mainly from items included by Coffey and Reichow (1987).

General visuo-perceptual tests. Most visuo-perceptual tests were conducted binocularly. The participants wore their corrective lenses if these were customarily worn for playing sport. The 12 tests were as follows:

1. *Static visual acuity*. This refers to the ability to resolve detail in an object when there is no relative movement between the observer and the target. It is typically specified in terms of the minimum angle of resolution of a test object that can be achieved at a given viewing distance. In this study, static visual acuity was measured both binocularly and monocularly for distance (6 m) and near (33 cm) using the Bailey-Lovie logMAR Chart. Visual acuity was scored letter by letter with each correct letter being counted as 0.02 log units.
2. *Dynamic visual acuity*. This is a measure of the ability of a person to resolve detail in a target object when there is relative movement between the observer and the target. Dynamic visual acuity was assessed using a modified version of the procedure described by Coffey and Reichow (1987). Two high-contrast black letters, the larger one from the 20/20 (6/6) and the smaller one from the 20/10 (6/3) line of a Snellen eye chart, were pasted onto a white disk, which in turn was affixed to the surface of a turntable. The turntable, which was positioned upright and at eye level, was controlled by a variable-speed motor capable of continuous angular velocity changes between 1 and 78 $rev \cdot min^{-1}$. The test distance was set at 1.5 m, resulting in static visual target resolution demand of 20/80 (6/24) for the larger target and 20/40 (6/12) for the smaller target. The apparatus was initially covered when the participants entered the experimental room and then the display was presented with the turntable rotating at its maximum speed. The turntable speed was progressively reduced and the participants were required to identify the rotating target letters, while maintaining a steady head position. The maximum rotational speed at which each letter was first correctly identified, averaged over three trials, was recorded as the measure of dynamic visual acuity.
3. *Phoria*. Phoria refers to the extent to which the axes of both eyes are in symmetry when viewing objects at different distances and is directly dependent upon the balance of the co-acting pairs of extra-ocular muscles. We assessed phorias in the horizontal and vertical planes using the Maddox Rod at the far distance and the Maddox Wing apparatus at the near distance. Phorias were measured in prism diopters with exophorias scored as positive values and esophorias as negative values.

4. *Accommodation*. When the viewing distance is changed, the focus of the crystalline lens of the eye must be altered by the action of the ciliary muscle to maintain maximum resolution; the lens becoming spherical for viewing near objects and flat for far objects. This change in eye focus is termed 'accommodation' and the effectiveness of this process can be assessed by determining the speed with which individuals can repeatedly adjust focus for different viewing distances. We measured accommodation by counting the cycles per minute that each participant could complete in accommodating to alternating presentation of ± 1 diopter prism flippers at a viewing distance of 50 cm.

5. *Vergence*. The ability to converge and diverge the eyes in viewing distant and far objects was assessed using a Risley rotating prism. Self-reported break-in and break-out points were recorded for letter targets and these were summed to provide measures of fusional reserves for image blurring, image breaking and image recovery.

6. *Stereopsis*. Stereopsis is the ability to discriminate differences in target object depth through the use of binocular disparity information. We assessed stereopsis by asking the participants to view standard random dot stereograms through red and green filtered goggles. The finest stereoscopic depth discrimination each individual was able to perform was recorded in minutes of arc.

7. *Depth perception*. Given that stereopsis is only an effective method for depth discrimination for objects within approximately 1 m of the observer, yet many sports require discriminations to be made at much greater distances, a second depth perception test (the Howard-Dolman test) was also conducted. The participants were seated 4.5 m from an illuminated box, within which were two moveable vertical uprights. The participant's task, without using head movements, was to align the two uprights using strings attached independently to each of the uprights. Three trials were conducted and depth error was measured as the absolute distance between the plane of the two uprights.

8. *Reaction time*. Both simple and choice reaction time were assessed using a configuration in which green light-emitting diodes were used to present visual stimuli and in which each stimulus light had a corresponding button for finger press responding. For simple reaction time, there was only one possible stimulus and one possible response (a button press with the right index finger). Reaction time was measured as the delay between illumination of the stimulus light and the individual's response. In total, 10 trials were presented in this condition, with the mean of the last five responses being calculated. For choice reaction time, there were four possible stimulus lights each with their own unique response key. Twenty trials were performed in this condition, with the mean reaction time being calculated for the five responses given with the right index finger (the same response as used for simple reaction time). In both conditions, foreperiod durations were varied so as to prevent anticipation. Using both conditions as data, decision-making rates (in ms per bit) were also computed for each participant by determining the slope of the stimulus information–reaction time plot.

9. *Field of view*. Sensitivity to visual stimuli across the broad field of view (Smythies, 1996) was assessed by determining the detection thresholds of each individual for stationary (static) and moving (kinetic) stimuli presented at various eccentricities. Stimulus presentation and data collection were controlled by a commercially available automated perimeter (Humphrey 630 Field Analyser; Allergan Humphrey, San Diego, CA). In the static condition, the participants maintained a central fixation while stimuli were presented randomly at each of 24 eccentricities along the horizontal meridian. Stimulus locations ranged in 6° steps from central vision (0°) to positions 72° in both the left and right visual fields. Detection thresholds were determined for each stimulus location. In the kinetic condition, stimuli were introduced along 12 meridians (three on each of the four viewing quadrants – left above the horizontal, left below the horizontal, right above the horizontal and right below the horizontal) and moved at a constant velocity of 0.07 $rad \cdot s^{-1}$ centrally until they were detected. In total, 12 stimuli were presented in random order to each individual and the spatial coordinates of each stimulus at the time of detection were recorded. These coordinates were then used to produce spatial maps, the areas of which provided the measure of kinetic field size. Two target stimuli of different size were used and separate area calculations were undertaken for each target size.

10. *Peripheral response time*. The ability of the participants to respond rapidly and successively to peripherally presented stimuli was assessed using the Wayne Computerized Saccadic Fixator (Wayne Engineering Orthoptic Division, Skokie, IL). Administration of the test was essentially as described by Coffey and Reichow (1987) with illumination set as recommended by Appler and Quimby (1984). The participants stood facing the apparatus, with the centre of the apparatus at eye height and within comfortable reaching distance of the response buttons. The lights on the apparatus were programmed to illuminate in random order and the task was to depress as many of the lights (response buttons) as possible within 30 s. After an initial practice trial, three test trials were administered and the best score for each individual (correct responses made in 30 s) was derived as a dependent measure.

11. *Eye movement skills*. The ability of the participants to make quick and accurate self-guided fixations and saccadic eye movements was assessed using a

projected King-Devick reading test. Each individual was presented sequentially with three different number matrices with the horizontal separation of the numbers in the rows of each matrix being varied at random. The task was to read these numbers aloud quickly and accurately. The time taken to read aloud all of the numbers in each of the tests was recorded, together with the number of reading errors. Although this test was originally designed for use in detecting eye movement difficulties in children, it was included because it has been advocated as part of visual profiling batteries for sports performers by Coffey and Reichow (1987).

12. *Coincidence-timing ability*. The ability to coincide a motor response with the arrival of a moving object at a target point was assessed using a Bassin Coincidence Timer (Lafayette Instruments Co., Lafayette, IN). The task was designed in an attempt to simulate the racquet sport requirement of timing the downswing of the racquet to coincide with the arrival of the ball in the contact zone. This task has previously been reported to benefit from generalized visual training (Vedelli, 1986). The participants were positioned either directly behind or slightly to the side of a 4.3-m linear runway along which apparent motion could be generated. They were required either to depress a hand-held response button or to swing a tennis racquet through a photo-optic beam so as to coincide the completion of their action with the moment of arrival of the apparent motion at the end of the runway. In total, 30 trials were administered in each response condition with each set of trials containing equal, but randomly ordered, presentations of stimulus motion of 5, 10 and 15 miles per hour (2.24, 4.47 and 6.72 $m \cdot s^{-1}$). These stimulus velocities are comparable to those typically used in both research and clinical practice using this apparatus and were chosen to present viewing times comparable to those in ball sports. Coincidence-timing performance was expressed as absolute accuracy (absolute error), directional bias (constant error) and consistency (variable error) (Schmidt, 1988). Negative scores indicated early responses and positive scores late responses.

Sport-specific motor test: Tennis forehand drive for accuracy. The criterion sport task used in this experiment involved the participants hitting a series of tennis forehand drives for accuracy. A Prince tennis ball projection machine was positioned 21.9 m from the participants and directed so as to deliver balls down the forehand line of the tennis court. The task was to play a cross-court forehand drive to the projected ball to land it in a circular target zone (3.5 m in radius) in the forehand court on the opposite side of the net. The participants were allowed as much warm-up and familiarization practice as they wished before undertaking a series of 30 trials from which the percentage of successful shots was determined. In half of these trials, the participants were on the move when striking the ball (from a starting position 3.25 m from the desired striking position); in the other half, they were stationary.

The tests were undertaken in three sessions. The ophthalmoscopy and the tests of static acuity, phorias, fixation disparity, accommodation, vergence, stereopsis, colour vision and visual field size were performed in a session lasting about 40 min, the remaining vision tests in a second session lasting 90 min, and the sport-specific motor test in a final session lasting approximately 25 min.

Data analysis

Each of the dependent measures of visual and motor performance was subjected to mixed factorial analyses of variance to determine if there were significant pre- to post-training changes and whether such changes were influenced by the particular group or training conditions experienced by the participants. Consequently, the between-individual factor of group membership (four levels) and the within-individual factor of time of testing (two levels) were included in the analyses for each of the visual and motor measures. Additional within-individual factors were included in the analyses for some of the variables. Target distance was included as a factor in the analyses for static visual acuity, phoria and vergence; target size in the analyses for dynamic visual acuity and kinetic visual field size; target eccentricity in the analysis of static visual field size; and plane of measurement (horizontal or vertical) in the analyses for static visual acuity and phoria. Exposure duration was added to the analysis of performance on the rapid ball detection task, task difficulty in the analysis of eye movement skills, and whether the participant was stationary or moving in the analysis of motor performance. The analysis conducted on coincidence-timing performance included response mode and stimulus velocity as additional within-individual factors. For all of these statistical analyses, an alpha of 0.05 was initially selected and then a Bonferroni adjustment was made as protection against inflated rejection of the null hypothesis (Johnson and Wichern, 1988). With 21 different analyses to be conducted, this gave rise to a corrected alpha of 0.0024 for the 95% confidence level.

Results

General visuo-perceptual tests

Static visual acuity. Table 1 shows the pre-training to post-training values of static visual actuity for each group, with separate figures provided for the binocular, right monocular and left monocular viewing at both the optically far and the optically near viewing distances. Negative values indicate static visual acuity better than 6/6 (or 20/20) and positive values denote static visual acuity worse than 6/6. A four-way analysis of variance (ANOVA) revealed significant effects only for the viewing distance factor ($F_{1,35} = 197.8$, $P < 0.001$), which was due to relatively poorer static visual acuity at the near viewing distance than the far one. Group membership had no impact on acuity overall ($F_{3,35} = 0.975$, $P = 0.416$), or in interaction with the time of testing ($F_{3,35} = 0.848$, $P = 0.477$) or any other factor in the experiment. We conclude, therefore, that the training regimens used by Groups 1–3 did not influence static visual acuity, nor was there any indication for Group 4, or any other group, of pre- to post-training improvements in acuity attributable simply to familiarity with the test procedure.

Dynamic visual acuity. The only significant effect evident in the statistical analysis of dynamic visual acuity was a predictably better performance by all participants for the larger target than for the smaller target ($F_{1,36} = 64.2$, $P < 0.001$) (Table 1). As with static visual acuity, there was no evidence of the visual training programmes causing any significant improvements in acuity. The group treatment effects had no significant influence on dynamic visual acuity either overall ($F_{3,36} = 1.71$, $P = 0.183$) or selectively on either the pre- or post-test ($F_{3,36} = 2.19$, $P = 0.106$) and there were also no significant higher-order interactions between groups and any other factors. The overall pre- to post-training changes in dynamic visual acuity were not significant ($F_{1,36} = 3.20$, $P = 0.082$), indicating minimal effects attributable simply to familiarity with the test procedure.

Phoria. A four-way ANOVA on phoria revealed a significant interaction between viewing distance and plane of measurement ($F_{1,34} = 108.0$, $P < 0.001$). This was due to significant exophoria in the horizontal plane at the near viewing distance, an effect not reproduced at the far distance or at either distance in the vertical plane (see Table 2). Horizontal exophoria at near viewing is a typical response and all values recorded were well within the accepted normal clinical range of ± 6 diopters. Importantly, in the current context, there were no significant effects due to the treatment conditions; the group factor did not approach significance either overall ($F_{3,34} = 0.841$, $P = 0.481$) or in interaction with time of testing ($F_{3,34} = 0.776$, $P = 0.516$). This indicates that the training regimens had no long-term, measurable impact on ocular muscle balance. There was also no indication of test familiarity effects on this measure, as the main effect for time of testing did not approach statistical significance ($F_{1,34} = 0.225$, $P = 0.638$).

Accommodation. Pre- to post-training improvements in accommodation, as indicated by a higher rate of accommodative changes per minute, were apparent for all groups ($F_{1,31} = 5.54$, $P = 0.025$) (Table 2) but failed to reach the corrected alpha level for significance. Pre- to post-training improvements were not selective, as there was no greater change for either of the visual training groups or the reading group compared with the control group ($F_{3,31} = 1.48$, $P = 0.239$).

Vergence. The break and recovery measures of fusional reserves both revealed identical statistical conclusions: a significant main effect for viewing distance ($F_{1,33} = 23.2$, $P < 0.001$ for the break measure; $F_{1,33} = 17.9$, $P < 0.001$ for the recovery measure) in the absence of any other significant effects. The distance main effect was due on both measures to greater fusional reserves at the near viewing distance (see Table 2). No overall group effects ($F_{3,33} = 1.55$, $P = 0.219$ for blur; $F_{3,33} = 2.08$, $P = 0.122$ for break; $F_{3,33} = 1.50$, $P = 0.233$ for recovery) or group effects selective to the time of testing ($F_{3,33} = 0.65$, $P = 0.588$ for blur; $F_{3,33} = 0.209$, $P = 0.889$ for break; $F_{3,33} = 0.498$, $P = 0.686$ for recovery) were apparent. This indicates that the training programmes experienced by the participants were ineffective in improving vergence.

Stereopsis. The stereoscopic data for each group are shown in Table 2 and, in all cases, are well within the normal range. Stereopsis scores did not differ overall between any of the groups ($F_{3,31} = 0.265$, $P = 0.850$) or as a function of the time of testing ($F_{1,31} = 1.44$, $P = 0.240$). Furthermore, there were no significant group differences in the pre- to post-training stereopsis score changes ($F_{3,31} = 0.585$, $P = 0.629$), indicating that none of the training programmes had impacted in any substantive way on this visual function.

Depth perception. The results obtained on the Howard-Dolman test of depth perception mirrored those obtained for stereopsis (Table 2). No significant effects for group were obtained overall ($F_{3,36} = 0.204$, $P = 0.893$) or selectively on the pre- or post-training tests ($F_{3,36} = 0.224$, $P = 0.879$). The visual training programmes, therefore, appear to offer no advantage in enhancing depth perception. Similarly, there was no main effect for the time of testing ($F_{1,36} = 1.075$, $P > 0.05$), indicating that the test was subject to minimal familiarity effects.

Table 1. Pre- and post-training values for static and dynamic visual acuity (mean ± *s*)

	Group 1: Sports vision		Group 2: Eyerobics		Group 3: Reading/placebo		Group 4: Control	
Measure	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
SVA								
RM (far)	−0.16 ± 0.10	−0.16 ± 0.14	−0.17 ± 0.09	−0.14 ± 0.12	−0.01 ± 0.21	−0.05 ± 0.22	−0.13 ± 0.08	−0.18 ± 0.09
LM (far)	−0.16 ± 0.10	−0.20 ± 0.10	−0.13 ± 0.11	−0.16 ± 0.15	−0.04 ± 0.28	0.00 ± 0.31	−0.03 ± 0.33	−0.07 ± 0.34
BIN (far)	−0.21 ± 0.10	−0.22 ± 0.10	−0.20 ± 0.10	−0.19 ± 0.12	−0.15 ± 0.19	−0.14 ± 0.20	−0.20 ± 0.07	−0.22 ± 0.08
RM (near)	0.09 ± 0.11	0.09 ± 0.14	0.16 ± 0.13	0.18 ± 0.10	0.20 ± 0.09	0.12 ± 0.06	0.16 ± 0.14	0.14 ± 0.10
LM (near)	0.09 ± 0.11	0.08 ± 0.11	0.18 ± 0.15	0.16 ± 0.11	0.23 ± 0.18	0.17 ± 0.23	0.24 ± 0.36	0.23 ± 0.35
BIN (near)	0.04 ± 0.07	0.06 ± 0.07	0.11 ± 0.11	0.12 ± 0.10	0.08 ± 0.10	0.05 ± 0.05	0.10 ± 0.09	0.08 ± 0.09
DVA								
6/12 Target	58.7 ± 8.7	62.2 ± 10.8	57.0 ± 6.7	64.6 ± 4.5	57.4 ± 7.7	53.9 ± 9.6	59.2 ± 7.1	61.8 ± 6.2
6/24 Target	66.9 ± 5.5	67.5 ± 4.9	66.3 ± 6.3	68.6 ± 4.6	64.4 ± 5.9	63.5 ± 6.0	66.2 ± 7.9	68.3 ± 4.5

Note: Static visual acuity (SVA) is measured in log MAR units and dynamic visual acuity (DVA) in $rev \cdot min^{-1}$. RM = right monocular, LM = left monocular, BIN = binocular.

Table 2. Pre- and post-training values for phoria, accommodation, vergence, stereopsis and depth perception (mean ± *s*)

	Group 1: Sports vision		Group 2: Eyerobics		Group 3: Reading/placebo		Group 4: Control	
Measure	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Phoria								
Far horizontal	−0.67 ± 1.6	−0.22 ± 1.6	−0.35 ± 0.8	−0.75 ± 0.6	+1.00 ± 3.9	+1.40 ± 4.8	−0.33 ± 1.0	−0.56 ± 1.1
Far vertical	+0.06 ± 0.4	+0.11 ± 0.3	0.00 ± 0.0	+0.10 ± 0.2	0.00 ± 0.0	0.00 ± 0.0	+0.11 ± 0.3	−0.06 ± 0.4
Near horizontal	+2.22 ± 2.0	+2.11 ± 2.2	+1.50 ± 1.0	+1.60 ± 1.4	+3.70 ± 5.8	+3.50 ± 5.9	+2.78 ± 2.0	+2.67 ± 1.9
Near vertical	−0.06 ± 1.7	0.00 ± 0.0	0.00 ± 0.0	+0.10 ± 0.2	0.00 ± 0.0	+0.50 ± 1.6	0.00 ± 0.0	0.00 ± 0.0
Accommodation	13.8 ± 3.8	16.1 ± 3.9	15.2 ± 4.2	14.5 ± 3.7	13.7 ± 5.9	17.6 ± 7.8	13.0 ± 2.7	16.0 ± 4.3
Vergence								
Far (blur)	24.9 ± 6.1	25.5 ± 7.8	22.3 ± 6.8	25.2 ± 7.0	22.3 ± 7.1	21.7 ± 8.0	20.1 ± 5.3	21.4 ± 8.6
Far (break)	18.8 ± 5.2	17.3 ± 5.7	20.0 ± 2.5	20.7 ± 6.2	21.0 ± 4.1	23.1 ± 6.3	22.8 ± 3.4	22.2 ± 6.5
Far (recovery)	13.6 ± 5.8	12.1 ± 4.9	17.1 ± 3.7	14.4 ± 5.4	17.0 ± 5.1	16.8 ± 2.9	18.2 ± 6.1	16.7 ± 7.3
Near (blur)	26.1 ± 4.4	26.9 ± 4.5	24.9 ± 5.1	26.9 ± 3.6	23.1 ± 6.4	21.8 ± 8.2	22.6 ± 7.7	24.9 ± 5.8
Near (break)	22.3 ± 4.2	24.1 ± 5.9	25.5 ± 2.7	26.6 ± 4.3	24.3 ± 4.3	24.8 ± 6.6	25.9 ± 4.3	26.4 ± 4.2
Near (recovery)	17.6 ± 4.3	17.5 ± 9.2	23.3 ± 4.7	20.1 ± 5.7	18.9 ± 6.2	18.4 ± 6.1	20.9 ± 6.3	20.3 ± 7.7
Stereopsis	39.4 ± 17.8	52.5 ± 31.1	37.5 ± 31.8	37.5 ± 31.8	45.0 ± 18.4	45.0 ± 34.4	33.8 ± 17.5	50.6 ± 33.0
Depth perception	3.3 ± 3.2	3.4 ± 3.6	2.4 ± 1.3	3.0 ± 3.4	2.7 ± 2.0	2.7 ± 2.6	2.3 ± 1.2	2.9 ± 2.3

Note: Phoria is measured in prism diopters, accommodation and vergence in cycles · min^{-1}, stereopsis in minutes of arc and depth perception in centimetres of error.

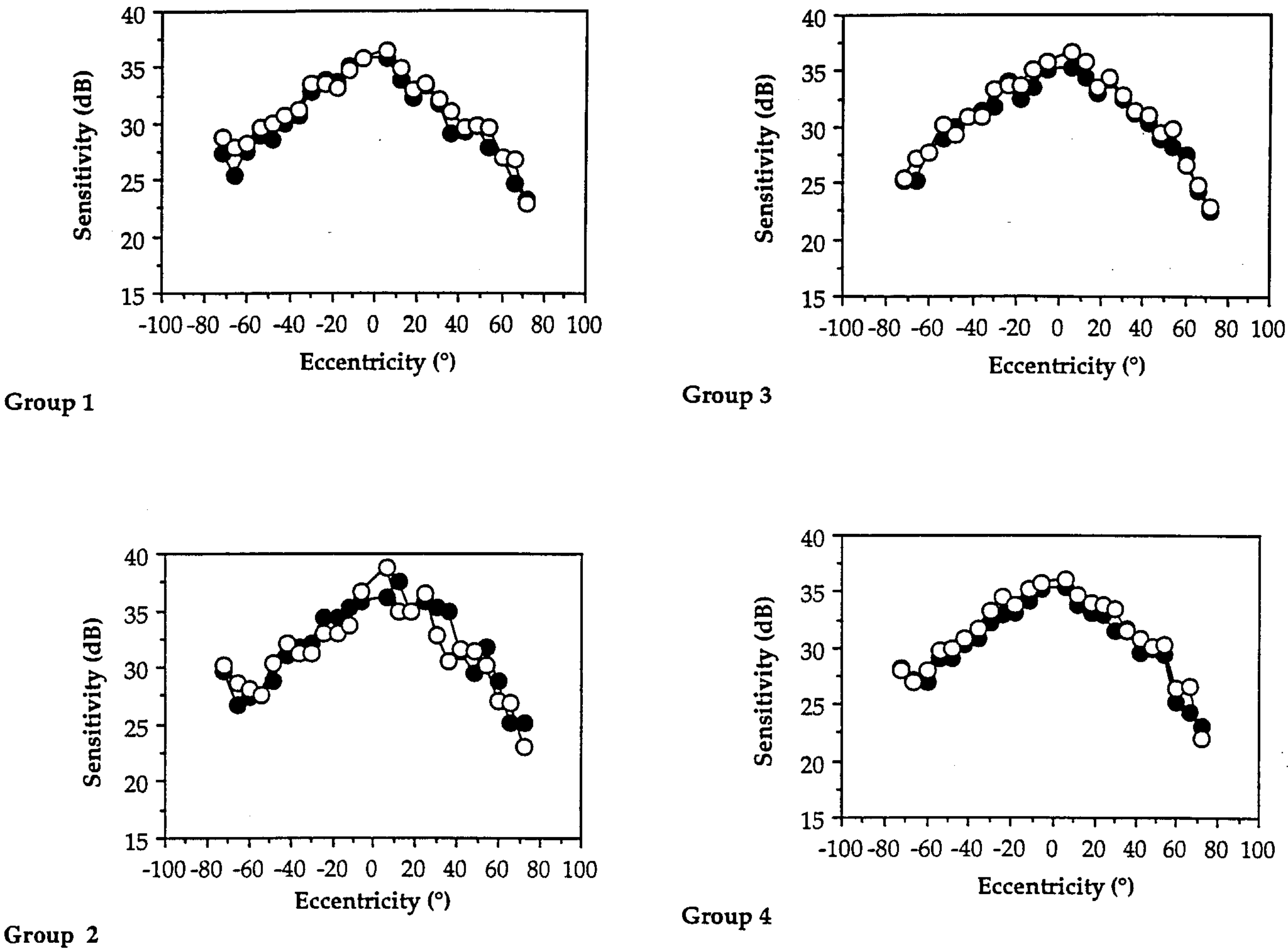

Fig. 2. Field of view sensitivities pre-training (●) and post-training (○) for each of the groups at each target eccentricity.

Reaction time. Simple reaction time did not alter significantly from pre- to post-training either overall ($F_{1,36} = 1.08$, $P = 0.306$) or selectively for any of the groups ($F_{3,36} = 0.159$, $P = 0.923$) (Table 3). There was a trend for choice reaction time to improve from pre- to post-training ($F_{1,36} = 7.30$, $P = 0.010$), but the effect occurred for all groups and was not simply restricted to those groups experiencing visual training ($F_{3,36} = 0.787$, $P = 0.509$). All improvements in choice reaction time, therefore, can be attributed simply to task familiarity and not to the selective effects of any of the training programmes.

Field of view. Plots of the sensitivities for static stimuli presented at different eccentricities in the left and right visual fields are provided in Fig. 2. No evidence was obtained of significant group effects either overall or in pre- to post-training changes in detection threshold. A trend existed for slightly better post-training sensitivities at some of the more peripheral locations (e.g. 60° and 66° in the right visual field and 66° in the left visual field), suggesting that there may be some familiarity effects in the test procedure. These effects were experienced by all participants and were selective to stimuli presented in the far periphery. None of the main or interactive effects for kinetic field size approached significance, indicating an absence of training and familiarity effects on this dynamic measure of visual field of view. As with the static test, no evidence was forthcoming to support the notion that the visual training programmes were effective in enhancing peripheral visual function (Table 3).

Peripheral response time. Peripheral response times, as assessed from best performances on the Wayne Computerized Saccadic Fixator, are presented for each group and for each time of testing in Table 3. A significant ($F_{1,20} = 30.6$, $P < 0.001$) effect for test occasion owing to systematic improvements from pre- to post-training was observed on this measure but the effect was not selective ($F_{3,20} = 0.388$, $P = 0.763$). All four groups improved their task performance signifi-

Table 3. Pre- and post-training values for reaction time, kinetic visual field size, and performance on the Wayne computerized Saccadic Fixator and the King-Devick test (mean ± *s*)

	Group 1: Sports vision		Group 2: Eyerobics		Group 3: Reading/placebo		Group 4: Control	
Measure	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Reaction time								
SRT	257.7 ± 41.4	265.9 ± 60.3	272.6 ± 55.7	264.2 ± 31.6	272.3 ± 37.9	264.6 ± 46.0	254.9 ± 21.0	255.8 ± 33.0
CRT	392.9 ± 60.9	380.7 ± 66.4	400.0 ± 56.0	375.4 ± 51.4	409.1 ± 64.9	397.7 ± 41.0	383.4 ± 53.8	339.7 ± 39.2
Decision-making	58.6 ± 34.8	57.4 ± 31.6	63.7 ± 23.8	55.6 ± 21.8	68.4 ± 27.7	66.5 ± 18.4	64.2 ± 29.1	42.0 ± 16.4
KVF								
Small target	5310 ± 545	6425 ± 318	5379 ± 1376	7256 ± 738	6270 ± 2004	5673 ± 610	7119 ± 1927	6149 ± 1113
Large target	11701 ± 748	11037 ± 1093	10914 ± 172	11640 ± 92	11410 ± 221	10776 ± 643	9971 ± 2964	11357 ± 419
WCSF	56.8 ± 9.5	62.5 ± 7.7	51.4 ± 6.4	61.0 ± 9.2	51.8 ± 3.6	60.5 ± 2.5	51.2 ± 4.1	59.0 ± 5.9
KD test								
Time	13.2 ± 1.9	13.7 ± 2.8	13.6 ± 1.4	14.9 ± 4.8	15.5 ± 2.6	15.8 ± 4.3	13.1 ± 1.7	13.1 ± 2.2
Errors	0.1 ± 0.4	0.6 ± 1.0	0.2 ± 0.4	0.5 ± 1.0	0.3 ± 0.6	0.7 ± 1.5	0.1 ± 0.3	0.1 ± 0.3

Note: Reaction time is measured in milliseconds (with decision-making rate in $ms \cdot bit^{-1}$), kinetic visual field (KVF) size in arbitrary area units, performance on the Wayne Computerized Saccadic Fixator (WCSF) in responses per 30 s and performance on the King-Devick (KD) test in both units of time (s) and error frequencies. SRT = simple reaction time, CRT = choice reaction time.

cantly from the pre-test to the post-test, again indicating that the improvements observed were simply due to familiarity with the test procedures themselves and not due to the effects of visual training.

Eye movement skills. Mean reading time on the King-Devick eye movement skills test (Table 3) was significantly influenced by test difficulty ($F_{2,72} = 9.30$, $P < 0.001$) only. The training programme experienced by the participants had no influence on task performance either overall ($F_{3,36} = 2.22$, $P = 0.103$) or selectively on either the pre- or post-training test ($F_{3,36} = 0.295$, $P = 0.829$). Similarly, there appeared to be no familiarization effects, with the main effect for test occasion being non-significant ($F_{1,36} = 1.18$, $P = 0.285$). These statistical conclusions were mirrored in analysis of the (relatively few) errors made on the task.

Coincidence timing. Analysis of absolute error, as a composite measure of timing performance, revealed a significant main effect for the response mode used ($F_{1,36} = 36.4$, $P < 0.001$) owing to greater error magnitudes under the racquet as opposed to the finger press response condition. Importantly, there was neither a significant test effect ($F_{1,36} = 0.084$, $P = 0.773$) nor a significant group × test interaction ($F_{3,36} = 0.459$, $P = 0.713$). No evidence was available, therefore, to support the contention that exposure to the visual training programmes would improve coincidence-timing ability. Similar statistical conclusions were reached from the analyses of constant error and variable error (Table 4).

Sport-specific motor test: Tennis forehand drive

Analysis of the accuracy measure from the tennis forehand drive task failed to reveal any significant main or interactive effects. Success rates were comparable across the stationary and moving conditions ($F_{1,35} = 0.087$, $P = 0.770$), as they were from the pre- to the post-training test ($F_{1,35} = 2.56$, $P = 0.119$) (Table 5). There was no difference in the performance of the four groups on this task on either of the test occasions ($F_{3,35} = 1.41$, $P = 0.256$), indicating that the visual training programmes (Groups 1 and 2) and the reading programme (Group 3) had been of no benefit in increasing performance on the sports skill task beyond that of the control group (Group 4).

Discussion

The use of generalized visual training programmes such as *Sports Vision* (Revien and Gabor, 1981) and *Eyerobics* (Revien, 1987) by athletes and coaches is based on the premise that such programmes can deliver on their claims of enhancing sports performance. This study was designed to examine these claims experimentally, as only anecdotal evidence exists to support their validity. If these generalized visual training programmes are indeed effective, then one should expect to see significant improvements in both vision and motor performance for groups of participants receiving visual training relative to groups not undergoing such training.

We noted earlier in this paper several reasons for scepticism as to the ability of generalized visual training programmes to enhance sports performance. These reasons are grounded in experimental assessment of the assumptions that underpin generalized visual training. First, generalized programmes aim to improve basic visual functions, yet these are not typically the limiting factors to expert performance. Systematic differences between experts and novices do not emerge on general visual function measures but do appear on many tasks requiring the interpretation and utilization of sport-specific information (Starkes and Deakin, 1984; Abernethy, 1987; Starkes, 1987). Secondly, training basic visuo-perceptual elements of performance in isolation from the specific movement elements of sports performance may be ineffective, given the importance of the close functional coupling of perception and action in skill production (Turvey and Carello, 1986). Thirdly, the attempt to gain improvements in specific aspects of sport skill using general forms of training violates the notion of specificity of practice (Henry, 1961), which is one of the oldest and most fundamental principles of skill acquisition. These issues are similar to those raised over the past decades by ophthalmologists against the use of vision therapy programmes for children with reading difficulties (Heiger, 1984; Cohen *et al.*, 1985). This particular study was conducted to examine systematically whether generalized visual training regimens could, in keeping with the claims of their proponents, induce significant changes in both visual and motor performance above and beyond the changes arising from either expectancy of improvement or physical practice alone.

Despite the claims made by the authors of the visual training programmes we examined, we were unable to find any evidence that such programmes actually work. Comparison with the performance of the reading (placebo) group (Group 3) and the control group experiencing only physical practice (Group 4) indicated that neither the *Sports Vision* programme experienced by Group 1 nor the *Eyerobics* programme experienced by Group 2 were able to produce persistent improvements in vision or in motor performance that could be attributed to selective exposure to the visual training. Pre- to post-training improvements in performance were evident on some measures (i.e. peripheral

Table 4. Pre- and post-training values for coincidence timing (mean ± *s*)

	Group 1: Sports vision		Group 2: Eyerobics		Group 3: Reading/placebo		Group 4: Control	
Measure	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Absolute error								
Button								
5 miles $\cdot$ h^{-1}	48.5 ± 30.8	39.2 ± 15.5	34.6 ± 9.0	39.4 ± 16.1	41.8 ± 25.3	36.7 ± 17.5	34.6 ± 11.4	30.9 ± 5.9
10 miles $\cdot$ h^{-1}	44.3 ± 20.3	35.3 ± 12.9	36.0 ± 8.8	46.9 ± 34.4	40.1 ± 16.2	33.9 ± 11.6	38.4 ± 10.3	34.5 ± 7.8
15 miles $\cdot$ h^{-1}	41.6 ± 19.6	37.8 ± 20.1	32.0 ± 12.3	44.4 ± 12.0	38.4 ± 16.5	38.5 ± 8.5	39.4 ± 7.0	42.9 ± 11.3
Racquet								
5 miles $\cdot$ h^{-1}	72.8 ± 27.9	78.2 ± 71.9	66.1 ± 17.7	55.2 ± 10.4	48.6 ± 12.7	57.1 ± 16.0	58.7 ± 12.7	76.3 ± 35.3
10 miles $\cdot$ h^{-1}	81.5 ± 71.1	53.4 ± 18.4	65.4 ± 22.7	55.8 ± 26.0	59.0 ± 32.0	54.4 ± 22.2	51.5 ± 21.3	50.5 ± 13.6
15 miles $\cdot$ h^{-1}	105.0 ± 108.3	99.2 ± 105.9	74.6 ± 29.1	61.5 ± 22.5	59.5 ± 27.1	73.4 ± 35.7	62.7 ± 32.3	72.8 ± 38.1
Constant error								
Button								
5 miles $\cdot$ h^{-1}	+21.0 ± 42.2	+5.0 ± 23.0	−4.3 ± 14.8	−5.3 ± 20.2	−13.3 ± 30.2	−11.6 ± 22.8	+10.2 ± 12.2	−5.1 ± 16.6
10 miles $\cdot$ h^{-1}	+10.3 ± 37.1	+6.3 ± 20.1	−7.8 ± 26.5	−2.1 ± 41.2	−16.6 ± 19.8	−12.9 ± 16.4	+4.1 ± 18.7	−4.7 ± 22.5
15 miles $\cdot$ h^{-1}	−11.3 ± 31.2	−0.2 ± 17.8	−4.6 ± 9.9	−2.5 ± 28.8	−6.8 ± 21.6	−16.6 ± 21.2	−12.4 ± 17.1	−26.4 ± 17.7
Racquet								
5 miles $\cdot$ h^{-1}	+41.0 ± 47.5	+29.3 ± 86.1	+22.6 ± 36.6	−10.0 ± 26.0	+1.5 ± 33.3	+12.6 ± 35.1	+16.6 ± 28.4	+6.1 ± 59.7
10 miles $\cdot$ h^{-1}	+62.0 ± 78.5	+31.6 ± 26.0	+36.7 ± 36.3	+19.0 ± 36.8	+26.5 ± 49.6	+30.4 ± 28.5	+0.3 ± 3.4	+5.0 ± 20.2
15 miles $\cdot$ h^{-1}	+89.2 ± 118.4	+93.3 ± 108.1	+69.7 ± 33.1	+43.4 ± 36.7	+39.5 ± 38.4	+61.8 ± 43.6	+21.6 ± 52.5	+50.2 ± 50.7
Variable error								
Button								
5 miles $\cdot$ h^{-1}	41.0 ± 23.0	42.5 ± 20.7	45.1 ± 17.6	43.1 ± 20.1	41.9 ± 26.0	42.0 ± 14.1	40.9 ± 16.3	37.8 ± 7.7
10 miles $\cdot$ h^{-1}	44.5 ± 23.1	39.6 ± 15.3	37.7 ± 14.1	53.5 ± 40.4	46.2 ± 21.7	38.2 ± 14.7	48.6 ± 11.7	40.8 ± 9.4
15 miles $\cdot$ h^{-1}	47.4 ± 21.0	47.0 ± 23.7	40.6 ± 15.8	51.4 ± 24.0	46.0 ± 19.8	40.4 ± 16.1	45.0 ± 5.9	44.0 ± 7.3
Racquet								
5 miles $\cdot$ h^{-1}	62.1 ± 23.3	93.2 ± 103.2	68.5 ± 21.5	64.3 ± 15.6	56.4 ± 15.8	63.1 ± 20.6	68.3 ± 21.0	81.2 ± 48.6
10 miles $\cdot$ h^{-1}	83.4 ± 102.5	55.9 ± 19.2	66.8 ± 24.5	65.8 ± 31.2	56.8 ± 15.9	52.4 ± 22.5	59.2 ± 23.0	61.8 ± 21.8
15 miles $\cdot$ h^{-1}	69.2 ± 90.2	75.0 ± 89.5	50.5 ± 10.0	58.8 ± 18.9	48.9 ± 28.2	50.7 ± 15.5	59.7 ± 21.4	59.4 ± 17.2

Note: Absolute, constant and variable errors measured in milliseconds.

Table 5. Pre- and post-training values for the motor performance task (mean ± *s*)

	Group 1: Sports vision		Group 2: Eyerobics		Group 3: Reading/placebo		Group 4: Control	
Measure	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Stationary	24.0 ± 18.1	34.0 ± 21.4	29.6 ± 20.3	34.1 ± 19.0	22.0 ± 18.6	34.0 ± 16.5	34.7 ± 21.7	38.0 ± 18.1
Moving	28.7 ± 20.4	29.3 ± 13.8	32.6 ± 20.7	29.6 ± 18.6	18.7 ± 18.3	35.5 ± 18.9	39.3 ± 21.4	32.7 ± 19.0

Note: The dependent measure in all cases is the percentage of correct/successful responses.

response time and static sensitivity to some peripheral field locations) and there were trends in this direction for others (i.e. accommodation and choice reaction time), but these improvements were experienced by all participants in the experiment and were due, therefore, to test familiarity and not due to the visual training programmes. Our findings are consistent with the concerns raised generally by ophthalmologists about the efficacy of vision therapy and consistent with the existing experimental examinations of other types of generalized visual training for sport (Wood and Abernethy, 1997).

There may be several reasons why the visual training programmes used in this study were ineffective in improving both visual and motor performance. An argument can be made that 4 weeks of practice may be insufficient to produce statistically significant training effects. However, such an explanation is unlikely, given the lack of any trends in the direction of better performance by the visual training groups. It is also noteworthy that the amount of training undertaken was greater than that specified by the authors of the training programmes as being sufficient for improvements to be observed. That the training was ineffective in inducing changes in basic visual function is probably due to the use of many training exercises (such as those involving viewing rotating spirals) that rely on visual illusions whose effects are transient. That the training was ineffective in inducing improvements in motor performance is also not surprising given the lack of situation specificity in the training tasks. However, it remains possible that more task-specific visual tests (such as eye movement recording during the actual act of hitting) may be necessary to tease out and demonstrate visuomotor improvements arising as a consequence of the visual training programme. Nevertheless, the training programmes' fundamental failure would appear to be that they attempt to train general visual factors that are now known not to be the limiting factor to sports performance. The findings and conclusions from this study are consistent, therefore, with those of Wood and Abernethy (1997), whose visual training programmes were administered in a more clinical, one-on-one fashion rather than relying on self-help approaches of the type used in the two training programmes examined in this study.

An important corollary question that needs to be addressed relates to why the findings from these controlled studies are at odds with the clinical anecdotes in which great successes are claimed from the use of visual training. We believe these discrepancies can be readily explained if the limitations in anecdotal reports are clearly recognized. First, anecdotes are necessarily selective and, as a consequence, represent a biased sample of experiences. Neutral or negative effects from visual training, which may occur with equal or greater frequency than positive effects, are unlikely to be reported because of their diminished importance to the clinician and patient (athlete) alike. Secondly, anecdotes necessarily reflect observer bias; clinicians with an intuitive belief in the benefits of the training exercises they are prescribing will be more attuned to look for possible facilitatory effects than to observe neutral or inhibitory effects. Thirdly, in the clinical context, where individuals are trained on the same apparatus on which they are tested, improvements in test performance that are simply due to familiarity with the apparatus and test protocol may be misinterpreted as genuine improvements in visual skills. Effects due to test familiarity cannot easily be separated from effects owing to training *per se* in dealing with single individuals, but can be readily discriminated in between-group experiments of the type conducted here, where control groups experiencing no visual training co-exist with experimental groups receiving training. In the current experiment, pre- to post-training improvements in such measures as choice reaction time and peripheral response time for individuals in the visual training groups could be misinterpreted as improvements due to the training, if it were not for the observation of comparable changes in the other (control) groups who were not provided with such training.

In the clinical context, the probability of placebo effects is also enhanced. Although significant placebo effects were not apparent in this study (i.e. Groups 3 and 4 did not differ systematically on any of the visual or motor measures), it is important to recognize that the participants in this study were non-athletes recruited to participate in an experiment rather than competitive athletes voluntarily seeking out professional help to improve performance. The motivation and personal investment in the training programme and its outcome, therefore, are likely to be significantly higher in the clinical context than the laboratory setting, exacerbating the potential for changes in sports performance that are due to positive expectation and self-confidence rather than improvements in vision.

In conclusion, the results of this experiment, coupled with those of Wood and Abernethy (1997), strongly suggest that generalized visual training programmes of the type advocated by sports optometrists should be used with caution by athletes and coaches. These programmes do not appear to provide the improvements in either basic visual function or motor performance relevant to sport that they claim to produce.

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