Visual adaptations to sports vision enhancement training

A study of collegiate athletes at the US Air Force Academy

Michael F. Zupan PhD, Alan W. Arata PhD, Alfred Wile MS and Ryan Parker OD

The concept of sports vision is a relatively simple one. The eyes feed sensory information to the brain, the brain interprets and integrates the visual data with other sensory information, and then sends out appropriate motor signals to the muscles.

If the visual system is not receiving messages accurately or quickly enough, performance may suffer[1]. It is important for visual systems to be functioning at advanced levels because athletic performance can be one of the most rigorous activities for the visual system[2].

The principle of training specificity indicates that athletes should train like they compete, meaning a cyclist will compete better in cycling if he/she trains riding the bike as compared to practicing running. Wilmore and Costill[3] take the Principle of Specificity concept one step further when they say, "The training program must stress the physiological systems that are critical for optimal performance in the given sport".

This statement indicates that specificity is anything that works a body system in conditions similar to the actual sport. To this end, weight lifting has been used to enhance performance in most sports and today, there is little debate as to the benefits of resistance training with respect to athletics. Sports vision is perhaps at the stage where weight training was 30 years ago. It is impossible to scientifically draw a direct link between weight training and enhanced athletic performance in a non-weight lifting competition; though it is a common belief that one exists. It would also make sense that training the visual systems of the body, working the muscles associated with eye movements, eye-hand reflexes and accommodation would enhance performance in sports that rely heavily on visual input.

The ability to catch a ball requires continuous convergence of the eyes, assessing the speed of the ball and predicting its path[4]. To actually catch a ball, one must combine the eye's inputs with activation of the body's motor system to get the hands in the correct place. Lenoir *et al*[5] showed that athletes with better depth perception would be more successful at catching compared to athletes with poor depth perception. Hoyt[6] states, "It would seem difficult to find fault with the concept of training biological systems to maximise their normal functions". This would be especially true when it comes to athletic performance.

Over the past few years, there has been an increase in utilisation and acceptance of sports vision training. However, there is still an unmet need for sports vision training at the high school, college and professional levels[7]. Not everyone is a proponent of vision training, perhaps as all people were not proponents of weight training 30 years ago. Concluding whether or not sports vision training, in a testing environment, results in better performance on the playing field is a difficult dilemma. Articles written by Wood and Abernethy[8], and Abernethy and Woods[9] claim that sports vision training is ineffective because the improved performance achieved after training is a result of test familiarity, although their sample size was very small. The real question here is, does training on a vision board, or other piece of sports vision training equipment, just make an athlete better at doing that piece of equipment or does it transfer to the real world? Like with most pieces of equipment, there is a learning factor regarding how the equipment works. Once individuals are familiar with the equipment, they tend to get better. Researchers expect these kinds of results. However, familiarity with a piece of equipment can only account for improvement during the first few tests/practice cycles. Long-term improvements should be attributed to changes in the body, whether mental or physical[10]. The purpose of this study was to look at possible long-term changes as a result of sports vision training.

About the authors

Michael Zupan, Alan Arata and Alfred Wile are all professors in the Human Performance Laboratory, Department of Athletics, US Air Force Academy. Ryan Parker practises at the Guthrie Vision Source/Oklahoma Sports Performance Center in Guthrie Oklahoma

Methods

Nine hundred and twenty-two athletes (759 males, 163 females), all intercollegiate athletes of various division one programmes that rely heavily on visual inputs, participated in sports vision training. The data used in this paper are retrospective, taken from records collected over multiple years from the United States Air Force Academy (USAFA) sports vision training programme. The retrospective study was approved by the USAFA Intuitional Review Board and subject confidentiality has been maintained.

Sports vision tests and training exercises were grouped into saccadic eye movements, accommodation, vergence and eye-hand speed and coordination. Prior to entering into the sports vision programme, each athlete completed a visual history questionnaire that asked about previous vision exam results, eye and hand dominance, significant ocular history, and the use of prescription eyewear or contact lenses.

Eye movements

Quick and accurate eye movements are essential to athletic success. Most sports require eye movement in a variety of directions. Saccadic eye movements are used to direct foveal fixation towards objects of interest[11]. Saccades depend on information from the periphery of the retina to tell the brain that there is something of

Photo 1
Horizontal and vertical saccade exercise

Photo 2
Plus/minus and prism flipper exercise

Photo 3
Near-far-near exercise for accommodative facility and vergence

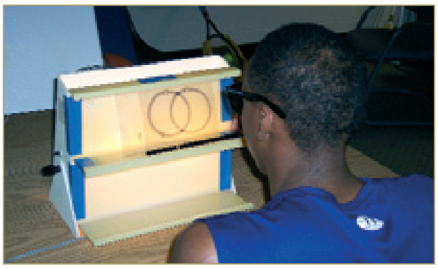

Photo 4
Testing with Quoits

Photo 5
Accuvision eye-hand coordination

Photo 6
Sports Vision Trainer (SVT) for eye-hand coordination

interest in the field that should be recognised[12]. Two saccadic eye movement protocols were developed to enhance visual skills. The first, horizontal saccades, was completed with each subject standing 2m away and centered between two charts (**Photo 1**). The charts were approximately eye level and were positioned 1.3m from the centre line. The charts are modified Hart charts with 10 letters/numbers per line using 36-pitch Arial font. Only moving their eyes, not their heads, subjects read aloud the first letter of the left chart and then the first letter of the right chart, then the second letter of the first chart followed by the second letter of the second chart. This continued for one minute. Scores were recorded as the complete number of cycles read in one minute (cpm). The second, vertical saccades, was repeated in the same manner in the vertical plane. Charts were switched on a regular basis to ensure familiarity with the material was keep to a minimum.

Accommodation and vergence

Vergence (fusion flexibility) and accommodation (the speed in which the accommodative system can change in response to different stimuli) work as eyes focus on objects coming from a distance, or as the field of focus quickly changes. Subjects performed four tests for accommodation and vergence. Plus/minus flippers work accommodative vergence facility. Subjects read aloud a card with multiple series of three random 12 pitch letters while holding the ±2.00D flippers before their eyes at 0.3m from the card (**Photo 2**). Each time the lenses were flipped, subjects read the next set of three letters. Subjects performed this for one minute and recorded the number of three letter sequences read.

Near-far-near charts were used to test accommodative facility and vergence ability. During this test, subjects used accommodative and convergence abilities to see letters up close (0.15m) followed immediately by letters at 6m (**Photo 3**). Starting in the upper left corner, one letter was read off the distance chart and then one letter (in the upper left corner) was read off the near chart. Subjects read the letters from left to right and recorded the number of letters obtained in one minute. Again, different charts were used on different training/testing sessions.

Quoits were used to test the limits of both the accommodative and vergence systems and were completed at a 0.4m working distance. Subjects wore polarised frames to separate the images seen by each eye. During the first part of the exercise, the Quoit sheets were moved to stimulate convergence (**Photo 4**). This meant the image seen by the right eye moved to the left and *vice versa* for the left eye. By moving these images in a base-out (crossed) direction, subjects were forced to use convergence in order to maintain single vision. The subjects moved the Quoits sheets until the single image split into two images. This was termed the 'break point' and it occurred when the vergence system could no longer maintain clear single binocular vision. Subjects then moved the Quoits sheets back together until they regained a single image. This point was termed the recovery point. Recovery occurred when both eyes were able to work together to produce the desired clear and single image. This exercise was repeated in the base-in direction, as subjects used divergence to maintain single vision.

The fourth vergence test, vergence facility, was performed with prism flippers. Subjects worked at a 0.3m distance using four prism dioptre base-out/base-in flippers. Groups of three letters were presented and subjects worked to make the letters clear and single before reading them aloud. Subjects then flipped the prisms and read a new series of three letters, this time with the opposite (base-out or base-in) from the previous trial. One cycle equalled two sets of three letters. This continued for one minute and the number of cycles was recorded.

Eye-hand coordination

Eye-hand coordination is essential to many competitive sports and was tested in the sports vision environment by using two pieces of equipment; the Accuvision 1000 (International Accuvision Systems Inc) and the Sports Vision Training (SVT) boards. The Accuvision board flashed a series of 60 lights (over the entire 1m by 1.3m board) in two different modes. The first test, fixator on, had the subjects attempt to touch the 60 targets (lights) at a speed of 2.78 targets per second (0.36 second per target) (**Photo 5**). The Accuvision recorded the number of correct hits, late hits and misses. This exercise challenged the subjects' reflexes and accuracy of central and peripheral vision. The second Accuvision test, fixator active, was set up like the first test (60 targets at the same speed), except this time a green fixator light in the middle of the board randomly illuminated. Subjects could only strike the targets when the green fixation light was on. If subjects touched a target when the green fixation light was off, a penalty was recorded and one point was taken off the response total. The number of correct hits along with late hits, misses, penalties and no hits (didn't hit went the fixator light was off) was recorded.

The third and final eye-hand coordination test used the SVT board (**Photo 6**). The SVT board displayed a centrally programmed sequence of 48 lights in the proactive mode. In this mode, the target light stayed on until contact was made. Time to hit the sequence of 48 lights was recorded to the hundredth of a second. Both the Accuvision and SVT boards randomised target order and location for every trial.

Results

All data were obtained from the described tests. Subjects' performances on each exercise were recorded, along with the number of training sessions the subject had completed prior to taking the test. Training sessions ranged from zero for new athletes to over 80 training sessions for some of the seniors that had trained consistently over a four-year period.

Both horizontal and vertical eye movements (saccades) showed improvement in the number of cycles obtained in one minute (cpm) throughout the training sessions. The greatest gains were seen during the first 20 sessions, but continued to increase with additional training. Vertical saccades started with an average baseline value of 28.22cpm and increased to a value of 38.89cpm (**Figure 1**), a 38% increase, after 61 or more training sessions.

Horizontal saccades showed similar improvement. **Figure 1** also shows the average baseline value was 29.52cpm. After 61 or more sessions, the average vertical saccade value was 38.54 cpm, a 31% increase in performance.

The number of cycles per minute (cpm) the subjects were able to obtain using ± flippers increased in almost a linear fashion during the sessions. The greatest improvements where seen in the first 20 training sessions, but improvements were still seen after 61 or more training sessions. **Figure 2** shows 65% increase in ± flipper facility with a baseline value of 16.89cpm, and a maximal session value of 27.82cpm.

The values for the near-far-near test are found in **Figure 3**. The greatest gains were realised in the first 10 training session. These initial gains were much greater than in any other exercise. Unlike the other exercises, the maximal values were seen between 21 and 30 sessions with a maximal value of 33.41cpm compared to a baseline value of 26.86cpm. This represents an overall 24% improvement in ability.

Subjects' accommodative and vergence systems showed vast improvement throughout the training sessions. **Figure 4** shows the break and recovery point values for Quoits in the base-out direction. The average baseline break point value was 26.80, with a corresponding recovery of 15.70. After more than 60 training sessions, the average break value increased to 46.26, which is a 73% improvement. The base-out recovery point value also increased to 40.04, which is a 155% improvement.

The results for base-in quoits are shown in **Figure 5**. The initial baseline breakpoint value was 12.49 with a recovery of 7.40. After maximal training sessions, the break value increased to 16.70 and the recovery value increased to 13.91. This resulted in a 34% improvement in the break point value and an 88% increase in the recovery.

Figure 6 show very similar results for prism flippers as was seen with ± flips.

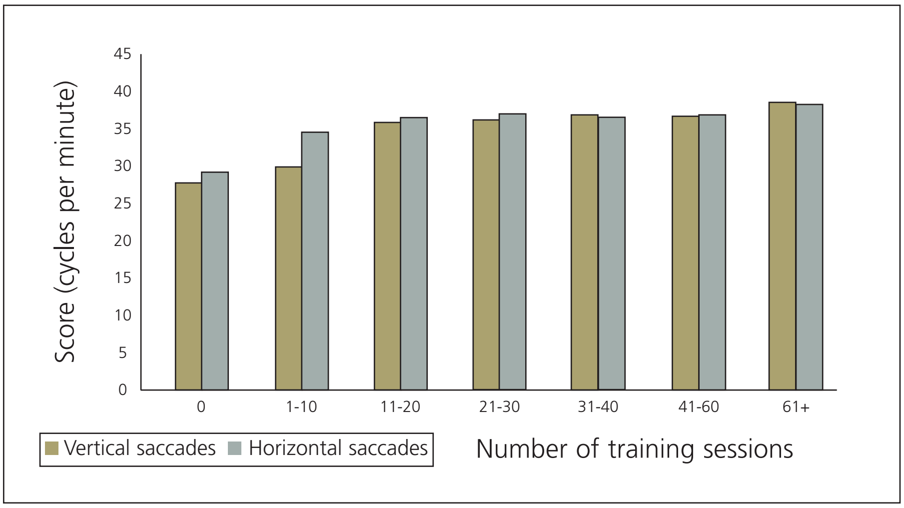

Figure 1
Vertical and horizontal saccades

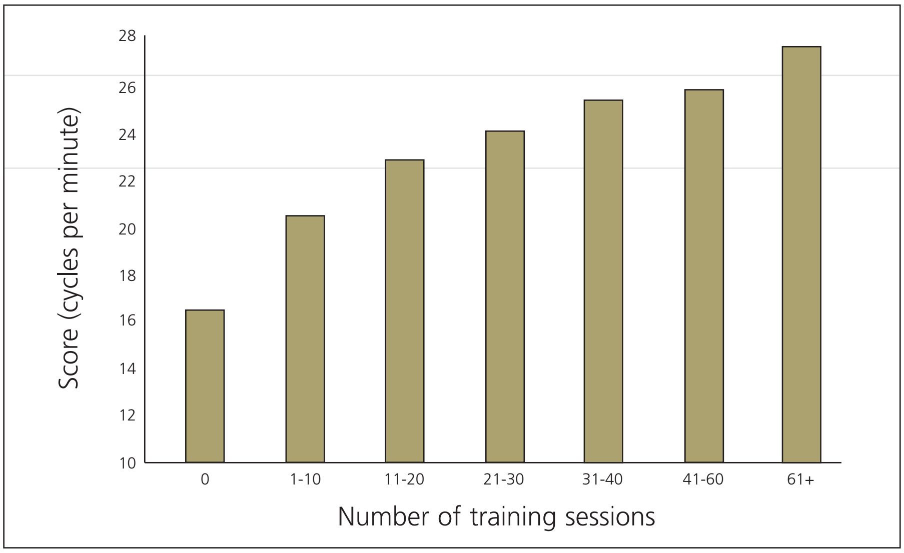

Figure 2
Lens flipper facility

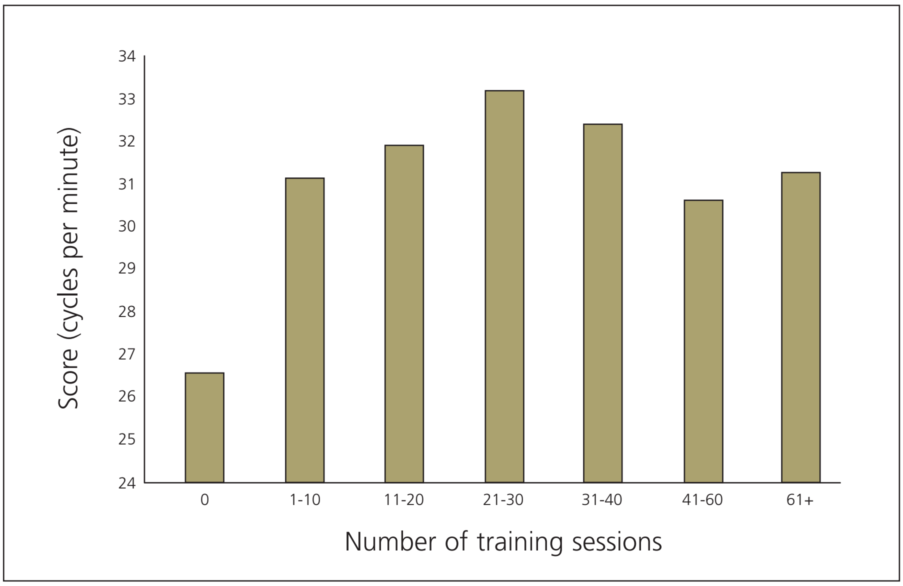

Figure 3
Near-far-near

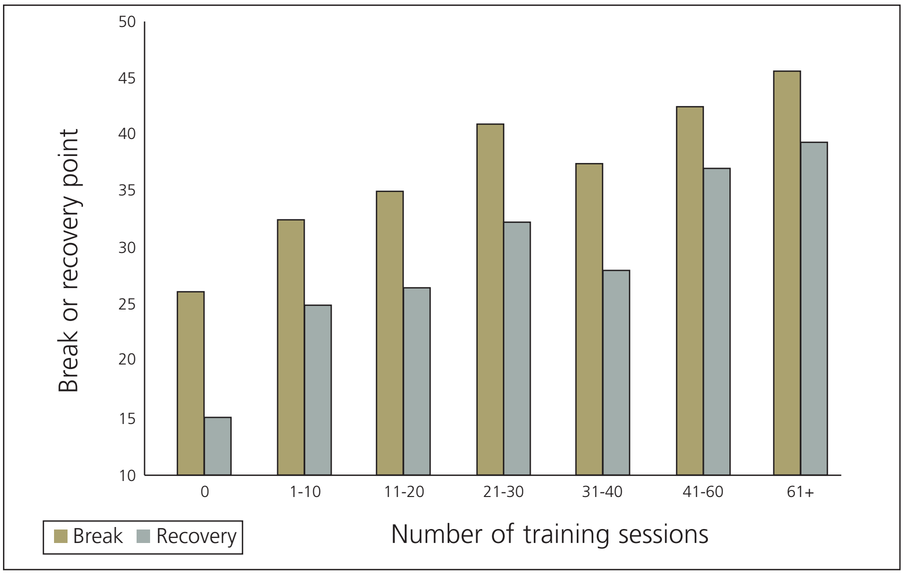

Figure 4
Quoits base-out

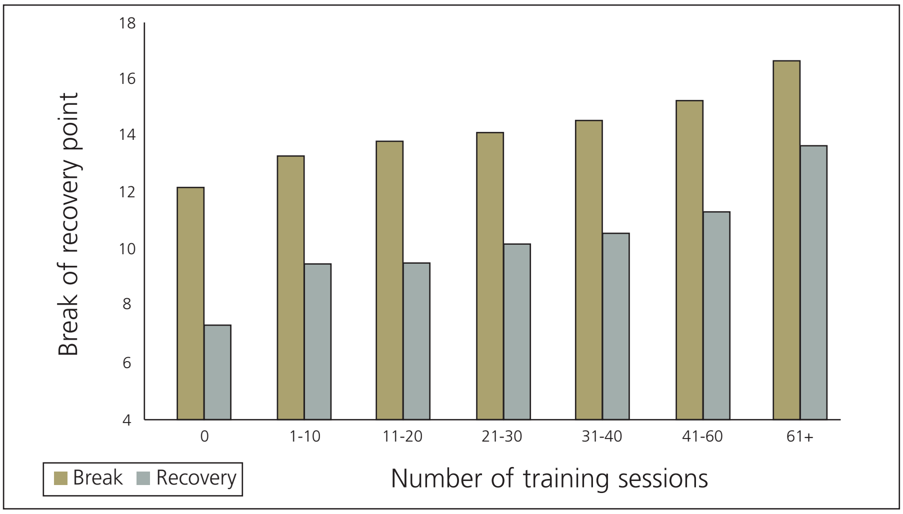

Figure 5
Quoits base-in

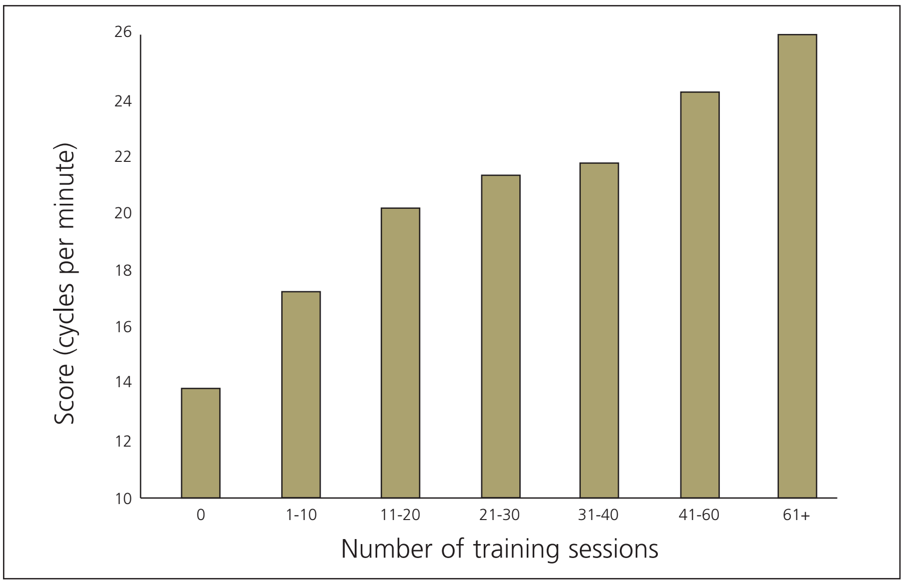

Figure 6
Prism flippers

There was an increase of 95% between baseline (13.28cpm) and maximal speed after 60 or more training sessions (25.94cpm).

The results for eye-hand speed and coordination showed similar changes as the results for eye movements, accommodation and vergence. **Figure 7** shows the overall results obtained for eye-hand reaction speed on the Accuvision 1000 in the fixator on mode. From the beginning of training to maximal sessions, the number of correct hits increased from 20.65 to 40.30 or a 95% increase. The number of misses shows a 74% decline from 28.98 to 7.67. The number of late responses held constant (10 to 13 late responses per test) throughout the training. This indicates that misses are likely becoming late responses, and late responses to correct responses as training progresses.

The data for the Accuvision 1000 in the Fixator Active mode are presented in **Figures 8 and 9**. The baseline score for correct hits during this exercise was 14.39. After maximal training sessions, the average score was 30.77 or a 114% improvement. Just like the first Accuvision test, there was a 72% decrease in the number of misses recorded as the scores dropped from an average of 20.82 missed to an average of 5.74 following training. Both the no hit and late responses stayed relatively steady throughout training. The trend in **Figure 8** is similar to the trend in **Figure 7**. As the number of misses decreased, the score increased leading to a faster and more accurate performance.

Figure 9 shows the number of penalties recorded during the Fixator Active tests. The average number of penalties recorded pre-training was 1.75. After 30 plus sports vision training sessions, the number of penalties decreased 78% to 0.39 penalties per test and remained relatively constant with increased training.

The results for eye-hand speed on the Sports Vision Trainer (SVT) are shown in **Figure 10**. The subjects averaged 19.11 seconds following training. This is 25% faster when compared to the 25.36 second baseline time.

Discussion

Vision skills are essential to success in most sports[13,14]. Visual sensory input may account for up to 85-90% of the sensory input an athlete is receiving during an athletic contest. This is especially true for athletes like hockey players, lacrosse or soccer goalies, baseball players and fencers. Beckermen *et al*[15] concluded that athletic populations at all levels could benefit from eyecare services, including sports vision training. The visual skills required by athletes will vary depending on the sport and even within different positions of that sport. If two similar trained athletes meet in competition and one has a better trained visual system, the athlete with the enhanced visual system will perform better[16].

The results indicate that an increased number of training sessions was associated with increased performance in each aspect of visual function that was investigated with the exception of near-far-near. This improvement most likely stems from repeated overloading and subsequent adaptation of the visual system. It was hypothesised that frequent training of the visual system should lead to stronger muscle fibres and more efficient neuronal responses, just as it does with other neuromuscular systems in the body. What was unknown was whether the adaptations made during training of the visual system would peak after a few sessions, or whether increased training would lead to greater adaptations. The results of this study would indicate the latter.

Increased training led to increased performance for all protocols tested. However, near-far-near improvements peaked out between 21 and 30 training sessions. It is unknown why this vision task is different than the others studied, however, it may have something to do with the human lens' ability to adapt and not the muscles associated with the lens. This particular aspect of the study indicates that athletes should not use training time to pursue further advantages gained by performing near-far-near tasks beyond about 25 sessions. The study does not conclude how long the training effect for near-far-near can be maintained, or how often near-far-near practice would need to be conducted to maintain the higher level training effect.

The fact that each vision task (except the near-far-near) improved, and improvement continued with subsequent practice, is the same concept and is exactly why athletic coaches have their teams practice throwing the ball or shooting a basket. When a human repeats an activity (practice/train), they become better at it from a sensory-neural-motor standpoint. Successful training requires practice and persistence until the neuro-musculo-skeletal systems are trained. The reasons behind why the visual system improves with training are beyond the scope of this study, but the bottom line appears to be that it does significantly improve with training. Since the visual and motor systems are invaluable to many athletic performances, they should be trained like any other body system that can enhance physical performance. Salmela and Fiorito[17] showed that performance precision with hockey players increased with accurate pre-shot visual cues. It should hold true that if a subject's visual system is at a higher level; their overall performance will be at a higher level as well[18].

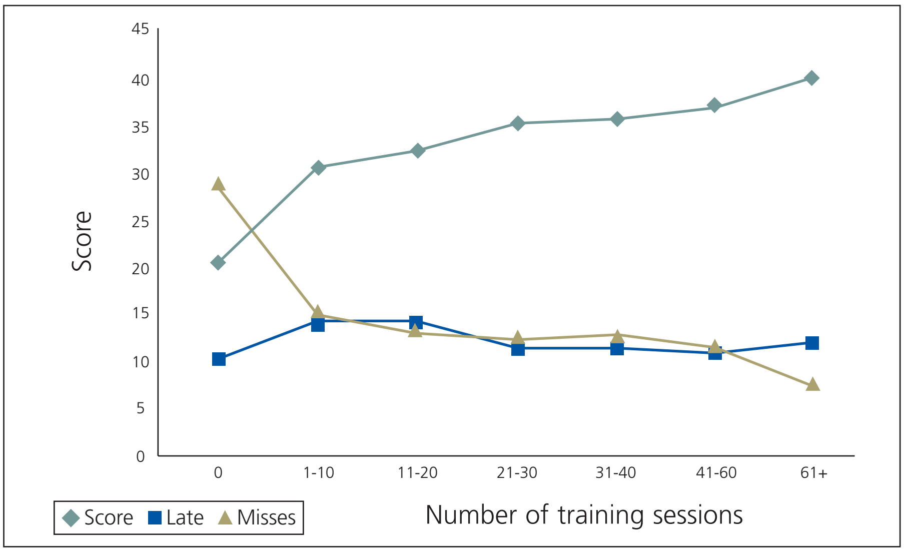

Figure 7
Accuvision

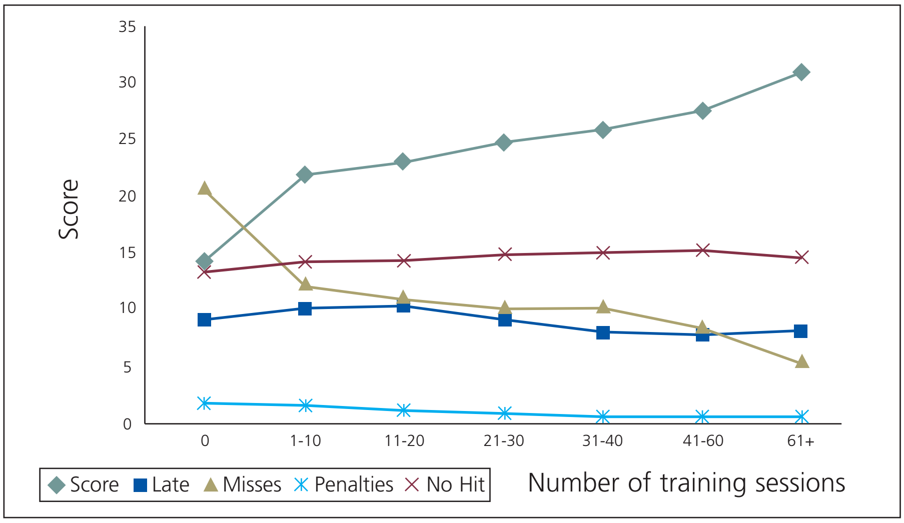

Figure 8
Accuvision (fixator active)

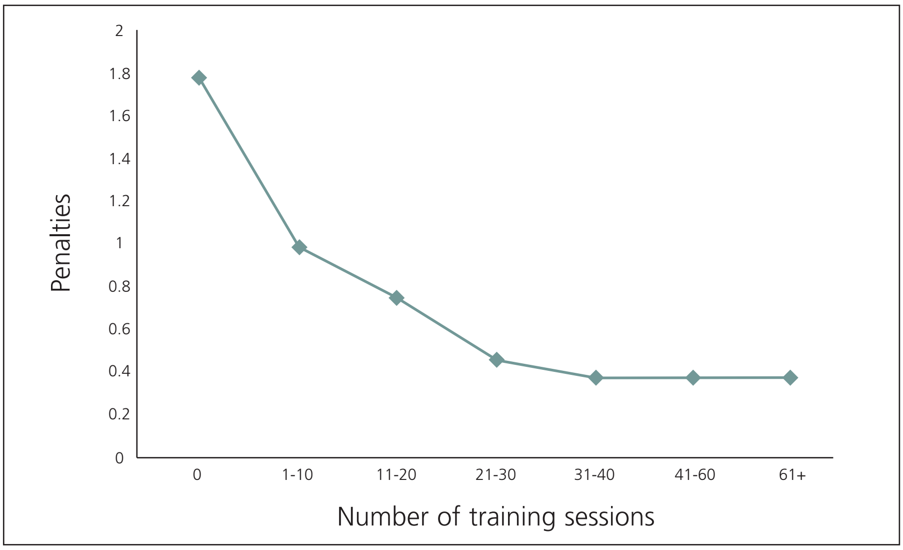

Figure 9
Accuvision penalties (fixator active)

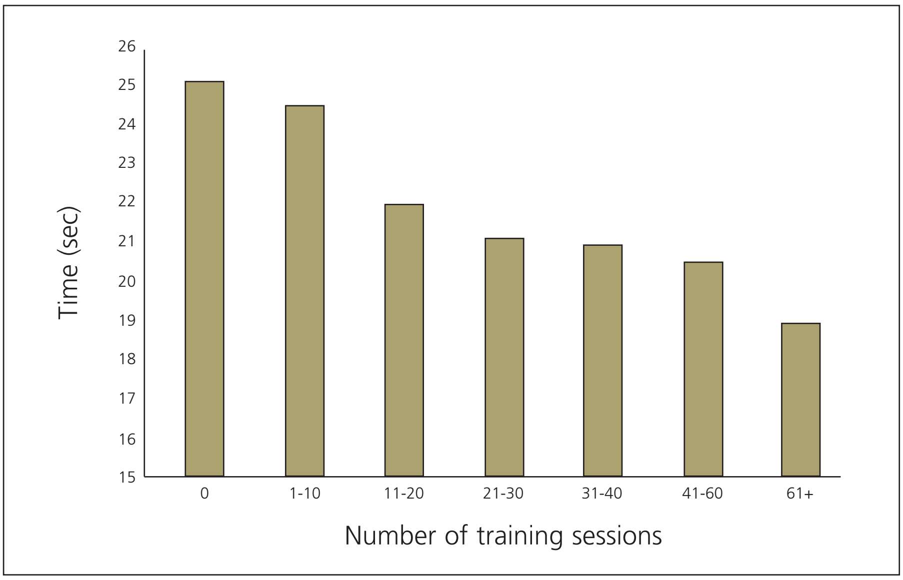

Figure 10
Sports Vision Training

Conclusion

The individual who can process more visual information in a shorter period and make the proper response will have an advantage in competition[19]. As athletes tap out their potential in other aspects of their performance, like speed, power or strength, what will they turn to next to increase their performance? The trend seems to be that they will turn to vision training. The results of this study indicate that if an individual performs vision training, then their visual systems will continue to improve with practice similar to other types of training.

Acknowledgement
The authors would like to thank Letitia H. Dawson, Tamara L. Payn and Megan E. Hannon for their help compiling the data and reviewing the manuscript.

Disclaimer
The views expressed in this article are those of the authors and do not reflect the official policy or position of the US Air Force, Department of Defense or government.

Author correspondence
Email: Michael.Zupan@usafa.af.mil

References

1. Berman A (1990) Starting a sports vision practice. *Optometric Management* 25: 30-4.
2. Hitzemen S and Beckerman S (1993) What the literature says about sports vision. *Optom. Clin.* 3: 145-69.
3. Wilmore J and Costill D (2004) Physiology of Sport and Exercise. Third Edition. Champaign IL: Human Kinetics, USA.
4. Regan D (1998) Visual factors in hitting and catching. *J. Sports Sci.* 15: 533-58.
5. Lenoir M, Musch E, La Grange N (2000) Ecological relevance of stereopsis in one-handed ball-catching. *Percept. Mot. Skills* 89: 495-508.
6. Hoyt C (1999) Visual training and reading. *Am. Orthopt. J.* 49: 23-25.
7. Zieman B, Reichow A, Coffey B (1993) Optometric trends in sports vision: knowledge, utilization, and practitioner role expansion potential. *J. Am. Optom. Assoc.* 64: 490-501.
8. Wood J and Abernethy B (1997) An assessment of the efficacy of sports vision training programs. *Optom. Vis. Sci.* 74: 646-59.
9. Abernethy B and Wood J (2001) Do generalized visual training programs for sport really work? An experimental investigation. *J. Sports Sci.* 19: 203-22.
10. Di Russo F, Pitzalis S, Spinelli D (2003) Fixation stability and saccadic latency in Elite shooters. *Vision Res.* 43: 1837-45.
11. Henderson J and Hollingworth A (2003) Eye movements and visual memory: Detecting changes to saccade targets in scenes. *Perception & Psychophysics* 65: 58-71.
12. Castet E and Masson G (2000) Motion perception during saccadic eye movements. *Nature America* Inc. 1-7.
13. Knudson D and Kluka D (1997) The impact of vision and vision training on sport performance. *JPERD* 68: 17-27.
14. Williams A, Ward P, Knowles J et al (2003) Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *J. Exp. Psychol. Appl.* 8: 259-70.
15. Beckerman S and Hitzeman S (2003) Sports vision testing of selected athletic participants in the 1997 and 1998 AAU Junior Olympic Games. *Optometry* 74:502-16.
16. Loran D and Griffiths G (2001) Visual performance and soccer skills in young players. *OT (Optometry Today/Optics Today)* 41; 2: 32-34.
17. Salmela J and Fiorito P (1980) Visual cues in ice hockey goaltending. *Can. J. Appl. Sport.* Sc. 4: 56-9.
18. Griffiths G (2002) Eye speed, motility and athletic potential. *OT (Optometry Today/Optics Today)* 42; 12: 34-37.
19. Adam J and Wilberg R (1992) Individual differences in visual information processing rate and the prediction of performance differences in team sports: A preliminary investigation. *Journal of Sports Sciences* 10: 261-73.