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STROBOSCOPIC VISION TRAINING: A HISTORIC PERSPECTIVE

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ABSTRACT

The use of liquid crystal stroboscopic sports vision training dates back to our introduction in 1995. With vision being the predominant sensory modality driving a motor response—whether hitting a baseball, shooting a basketball, a goalie stopping an incoming puck hurtling towards him—coaches, sports psychologists, researchers, and sports vision doctors have worked to develop strategies to improve performance. What can be measured for the entire neuro-visual processing? Can you improve this processing? If so, what are the most effective regimens? How long does it last? What is it that the athlete visually discriminates on for meaning and expertise? Saccadic eye movements are the most common visual skill for acquiring a target. When making these eye movements, the brain 'masks' the visual world for a few milliseconds until the eye come to a stop. This is known as saccadic omission and suppression. Are there effective strategies to minimize the effect and speed up the saccadic eye movements? Can we improve fixation accuracy? Decrease latencies? Improve target acquisition, sometimes referred to as dynamic visual acuity? A body of research quickly uncovers what stroboscopic vision training (SVT) can and cannot impact. Both anecdotal and statistically significant research studies shed light on SVT enhancing central visual processing, visual concentration, and athletic performance tied to the subskills impacted by SVT.

Keywords: strobe glasses, vision, vision training, performance enhancement

INTRODUCTION

In the book, *Better: A Surgeon's Notes on Performance*, by Atul Gawande, MD, each chapter documents substantive efforts to improve performance in varied fields.[1] This unrelenting drive to improve—whether a surgeon, a cab driver, a manufacturer–is woven into the makeup of society. What does 'better' look like as an optometrist

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involved in vision performance? Since forty percent of the brain solely deals with vision,[2] can we learn to see better, visually process more quickly and adequately, and perform visually guided tasks more efficiently? If so–how? The process of translation from light to visual understanding and subsequent motor response is fascinating. There are inaccuracies, discrepancies between the eyes, lag times between stimulus presentation and response while the process ensues.

BACKGROUND

The visual system begins, obviously, with the eyes. Light is focused through the optics of the cornea and crystalline lens, passing the light to the retina. You have between 110 and 130 million photoreceptors (rods and cones) per eye, within the layers of the retina. They release a photochemical, rhodopsin. Layered like lilies on a pond is a network of approximately one and a half million nerve fibers that soak up the photochemical, stimulating an electrical output that travels within milliseconds into the brain for processing. Latency and amplitude of this signal can be measured. Still, the amazing aspect is from this electrochemical transmission, we derive in real-time motion, color, inference, clarity, and, often meaning and understanding. Of critical import is keeping the image perfectly centered on the fovea. If the observer's object, eye, or movement displaces the target just the slightest amount, blurring can take place, depth, and spatial awareness is compromised, and the motor response is thwarted.

Internally, there is a focusing system, referred to as accommodation. Akin to a trampoline which comprises three elements (metal frame, springs, and canvas)- the focusing muscle is known as the ciliary muscle, which attaches to zonular fibers. The crystalline lens is analogous to the canvas of the trampoline, while the ciliary muscle would mimic the metal frame, the zonular fibers, the springs. As a target is brought closer and closer, focusing increases, and eye movement occurs, known as accommodative vergence. The autonomic nervous system controls the human focusing system. External to each eye are six extraocular muscles. These muscles fulfill the binocular alignment, convergence, divergence, depth perception, stereopsis, and the human tracking skills of smooth pursuit and saccadic eye movements. The central nervous system controls these extraocular muscles, hence tracking and binocular vision. The eyes are one of the only places in the body where the central and autonomic nervous systems are innervationally connected. Known as the AC/A ratio, the effect is when accommodation is increased, it innervationally causes the binocular vision to converge.

Similarly, if you converge your eyes, increased accommodation is elicited. This is one of the elements of neurologic processing that enables vision. Depth perception unites with eye alignment and peripheral visual awareness.

The tracking system and their neural substrates are critical to this paper. Let me start with an example. Suppose you are playing tennis. You hit a forehand shot towards your opponent's backhand. Watching the other players' response, you note they get a delayed jump towards the ball. Sensing they will not be able to get much force to their return shot, you decide to move up into the court for a possible kill shot. Getting into the forecourt, you track your opponent as he strikes the ball. He has decided to try a lob shot over your head. You rapidly rotate your head and body (along with your tracking eye movements) to follow the ball. Cuiffreda and Tannen describe this well.[3] These retinal, ocular and combined head and body movements primarily stimulate (1) the saccadic system to attempt to acquire foveation, (2) the pursuit system to match eye velocity to the velocity of the smoothly moving target, (3) the vestibular system to stabilize gaze during the initial transient phase of head and body rotation, and (4) the optokinetic system to stabilize gaze during the later, sustained phase of head and body rotation. This visual processing through the tracking system is quite sophisticated. As mentioned, garnering information through the visual system is most effective when images are held

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steady on the retina. Images moving over the retina at even a low rate of speed degrade visual acuity. Add concurrent head and body movement, and the potential for retinal image disruption escalates. Rapid judgment of distance, depth, size, and object orientation, referred to as motion parallax sensitivity, absolutely depends upon the stability of retinal images.[4] The fovea (the macula's central structure) is the clearest vision point. This area takes up less than one percent of the retina and is the only place where one can see down to one minute of arc or smaller. Maintaining retinal image integrity, i.e., keeping the image focused upon the fovea (foveation), is the tracking system's overarching sole purpose. The various components of vestibular, optokinetic and visual fixation systems **hold** images steady on the retina. Smooth pursuits, saccades, and vergence eye movements work to **shift gaze** onto the fovea.

STROBOSCOPIC VISION THERAPY (SVP) PREMISE

We know that, with training, accuracy can be improved, speeds can be improved upon, as can latencies. Right Eye, Inc., (www.RightEye.com) utilizes high-speed eye tracking, and their data capture system is reproducible, allowing for change analyses. Further, since their database is so enormous, they have received FDA approval to provide metrics that show how your tracking metrics compare for others your age. A recent article[5] using Right Eye technology showed how oculomotor skillsets were predictive for professional baseball batting performance. The data now suggests that tracking skill sets can be readily improved upon.

Pursuit movements originate in the parietal lobe and cerebellum. The faster tracking system, saccades, derives from the frontal lobe, cerebellum, and motor control nuclei (dorsal vermis) in the brainstem. While a subject utilizes pursuit movements to track an object moving slowly, the visual processing is 'steady state on'. Saccadic eye movements, on the other hand, are substantially faster. The typical elicitation of a saccadic movement is, on average, a delay of 200 msec after the presentation of the stimulus.[2,3] Express saccades have a delay of just 100 msec. which is akin to a batter attempting to time a fastball. Saccades can reach velocities of up to 500 deg/sec. There is also a frequently measured "slippage" between the two eyes as a saccadic eye movement occurs, known as pulse dysmetria. But, one of the most intriguing aspects of saccadic eye movements is saccadic suppression and omission. The brain effectively visually masks the neural noise. The key here is the brain is not 'steady state on' during saccadic eye movements, as it does not process the visual information concurrently with the saccadic movement. The subject uses their peripheral or peri-central vision to acquire the target. Then, the brain estimates the location, and the eyes rapidly move to the desired area (hopefully). This can be as simple as a shortstop peripherally acquiring the first baseman after fielding a ball hit to him, making the requisite rapid saccadic eye movement followed by the motor response of throwing the ball. Or perhaps a basketball player quickly locks onto the basket rim peripherally, then snaps the saccadic eye movement onto the rim, landing there long enough to calibrate their shot. This could also represent a driver making rapid saccadic eye movements from oncoming traffic to cars in their lane, then to gauges, and back to a road sign. Saccadic eye movements are used when reading- -peripherally finding the next 'sentence fragment', then making the quick saccadic eye movement. This is illustrated in Figure 1.

Here is a simple fixation target. Select a target to follow with your eyes. Track the target as you move it slowly from side to side over a 6 to 8-inch distance. While fixated on the target, notice the background beyond the target. You should see it appear to move opposite the direction of the target trajectory.

For saccadic eye movements (Figure 2), select two targets to view. Here you separate the targets the same distance you had for the smooth pursuit movements (6-8 inches). Fixate on the left target. Now, find the right target in your peripheral vision. Once you find the right target in your peripheral

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FIG. 1 Smooth Pursuit Tracking.

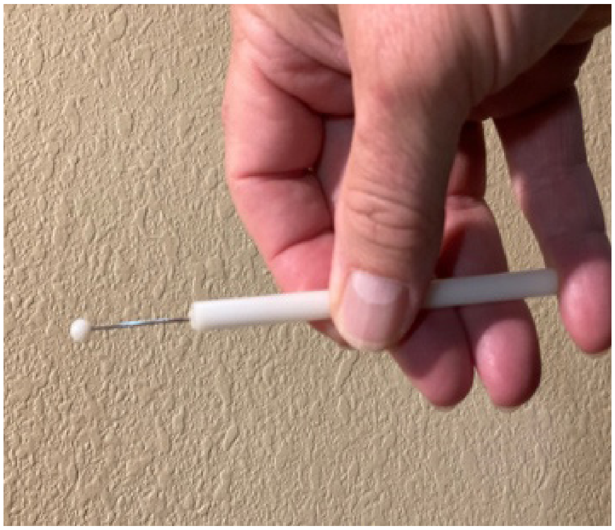

FIG. 2 Saccadic Eye Tracking.

vision, ‘snap’ your eyes quickly to the right one. Repeat the process, making the saccadic eye move to the left target. As you ‘oscillate’ back and forth, please be aware of background movement. You will note that the background does not appear to move as it did while making the smooth pursuit movement. This filtering is what was earlier described as saccadic suppression and omission. In effect, once the peripheral target Is acquired, the brain locks in the image of the first target. The eyes make the rapid eye movement shift to the second target. Once the target appears to be acquired, the brain resumes processing its’ central vision. If the eye movement is not adequately aligned, then a short adjustment of saccadic eye movement occurs—before central vision is restored. This is referred to as either undershooting or overshooting. This short period of processing ‘disruption’, which the brain attempts to mask and filter out visually, keeps the distractions down, allowing the person to concentrate more effectively.

So why is this of interest? The reason is that when tracking a baseball, you cannot maintain fixation on the ball from when it leaves the pitchers’ hand and crosses the plate. The better hitters in baseball begin to recognize the pitch- a curveball, slider, fastball or change-up, literally milliseconds from the release point. Then, the effort is to make a saccadic eye movement and re-acquire the ball, hopefully near the contact point of bat meeting ball. Just like while reading, the brain uses the visual information before making the saccadic eye movement. Then the brain ‘fills in‘ the gap. The goal is to utilize stroboscopic vision training (SVT) to help refine the visual information needed before saccadic suppression is initiated, then to work for faster and more accurate saccades, with improved fixation stability so once visual processing resumes, it does so at a faster and more discerning rate.

Ask a baseball, tennis, or softball player if they watch the ball to their bat or racquet, and the likely response is absolutely! Or the volleyball player working to dig out a kill shot. “I watched it all the way!” many will emphatically insist.

With competitive sports, the higher the level, the game, in essence, speeds up. This places greater demands on the human visual system. Acting and responding accuracy depends on a measured focus upon reliable information from the playing environment. Thus, it follows that maximum performance critically relies on rapid, distributed, and precise visual perception and attention abilities. An essential aspect is the role of visual feedback –rapidly

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assessing and updating objects' relative movements, distances, and masses in the visual environment to gauge the appropriate force required for a successful motor response.[6]

Motor actions are guided by a combination of cognitive planning and feedback from the visual system updated in as close to real-time as the surrounding environment dictates. Research investigating the role of feedback on visual-motor control has demonstrated that movements become progressively more visually guided as the athlete shows improved performance.[7] Another significant element in athletic events is that of balance. Many visual fibers synaptically connect to the inner ear for balance. The parvocellular and magnocellular layers are two major cortical neuron bundles that deal with vision. The magnocellular layer involves balance, spatial awareness, and depth perception. When one gets out of balance, there is a strong intrinsic 'pull' to quickly look down at the surface beneath you to right oneself. In almost all team sports, the elite players can perform at a high-level despite being out of balance. Whether this is a wide receiver diving to make a catch, or an NBA player getting an accurate shot off while their body is horizontal and will shortly hit the deck, the reality is that when one gets out of balance, the neural 'wiring' lights off in an attempt to regain proper balance. The pull to move from peripheral vision to central vision is a strong one.[2,3]

In this author's experience, I have been intrigued by professional baseball players commenting on how, during short stretches within the season, the ball appears larger and slower—allowing them to hit with increased visual-motor control. Then, in the next sentence, contrasting this with times when they had trouble picking up the ball, describing the ball as zooming by. Or a quarterback who compared moments when he could read the defense and throw accurately to a receiver seemingly in slow motion, as opposed to other times when everything seemed to be in frantic motion, disrupting his ability to concentrate and read the surroundings.

Given this, I began to explore the implications if visual feedback was interrupted, providing the athlete substantially less time for visual feedback and decision-making. Akin to running a car up to 120 miles per hour, the surroundings are first 'flying by'. However, the brain quickly adjusts in concentrated dynamic visual acuity and tightens down the visual feedback loop to acclimate to the heightened speed. Slowing down to 55 miles an hour, the driver routinely reports how slow the environment is going by.

Testing this, I had the opportunity to work with a community college football team. College footballs have two white stripes on the ball. We would take the receivers and defensive backs into the wrestling room (no windows), turn out the lights, and light the room with four theatrical strobe lights. As the athletes acclimated to the visual demand, the strobe light was slowed to where the oscillating light was 'on' less and less. The sports euphemism, *watch the ball all the way into your hands,* was forced to be adhered to. Anecdotally, the coaches found this helpful, and continued to add this to their weekly practice schedule. Next, I worked with two defensive backs and a running back for an NFL team. This use of strobe lights was one of the more impacting therapies I could deploy. At this same time, I was working with an NBA first-round draft pick who was quickly being slapped with the moniker of having 'bad hands'. I spent hours with him, the strobe light flashing and working on catching tennis balls and basketballs. I could use the team's practice facility for on-court work, but this was onerous, and it was hard to schedule time availability. I began to think of how much simpler it would be if I had glasses that would work for this. Baseball players could use them for hitting off a tee, soft toss, and batting practice. Tennis players could play on their practice courts, and football players could run on their fields rather than a dark room that took them away from their teammates in practice.

Rather than using flashing lights, would high-speed liquid crystal suffice? What would the duration of the opaque phase be? The clear phase? I was able to coordinate with a business person. We received a patent (5,478,239) and developed several prototypes before the commercial StrobeSpex version. I used

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these with several NBA players, professional women's tennis players, and my contacts at the NFL's San Francisco 49ers. With this serving as proof of concept, we committed to spending to obtain the frame molds, liquid crystal 'lenses', battery units, electronic circuitry, packaging, and marketing materials. We filmed our marketing video with testimonials from several players and coaches from the San Francisco 49ers. Unfortunately, shortly after the commercial version of StrobeSpex were delivered, I had to leave the company we had formed.

A few years later, Nike came out with their Vapor Strobes. Nike negotiated with my former partner to buy the patent. Shortly after that, Nike decided to drop out of the diagnostic and therapy space. Senaptec, Inc. bought out the Nike group of products involved in sports vision. Fortunately, Senaptec strobe glasses and their sensory station continue to improve and are readily available.

So, what is the applicable research in this space teaching?

In 1995, we initially worked with Sacramento City College baseball and their coach, Jerry Weinstein. Jerry was also a manager for the Dodger's single-A affiliate and assistant coach to USA Baseball. He was intrigued and allowed us to take four of his players who were starters—but had lower batting averages—to see if there would be an effect. The average increase was 56 points after 6 weeks. Since this clearly was not a placebo-controlled, randomized, double-blind study, the results would not pass scientific de rigueur.

In 1996, Sierra College's Denise Stone, MA, worked with Kelly Hankins on her CSU, Sacramento Master's Thesis, *The Effects of Using StrobeSpex as a Training Tool to Improve Hitting Efficacy in Collegiate Baseball Players.* Although unpublished, and her subject pool collapsed from 41 baseball team players to 14 who completed the 6-week course, Hankins made several inferences. While the statistical data set leaves validity open to question, the players in the two groups using StrobeSpex improved their batting averages, one at 60% improvement and the other at 72% gain. The control groups improved 22.7% and 25%, respectively.

Fortunately, academic researchers began to set up better-designed studies. Early studies looked at visual occlusion—how little of the visual information the athlete needs before the performance begins to erode. Moreno et al[8] found that the more experienced athletes garnered more information visually. As increased occlusion occurred, the authors report that nonexperienced athletes made significantly more errors.

One of the foremost authorities in stroboscopic training is L. Gregory Appelbaum, PhD from Duke University. In their 2011 article, Appelbaum found that SVT *can increase the ability to quickly process visual information in the central visual field*.[9]

In a follow-up article in 2012, Appelbaum, et al found that stroboscopic visual training improved information encoding in short-term memory.[10] Also in 2012, Clark, et al published in PloS ONE that sports vision demonstrated that a sports vision training regimen that included stroboscopic vision training improved the University of Cincinnati's baseball team batting average from 0.251 in 2010 to 0.285 in 2011. Both hitting and slugging percentages improved. This was juxtaposed against the rest of the Big East conference's 12 baseball teams, who saw their team batting average fall slightly. While this cannot be attributed just to stroboscopic therapy, the data in quite robust.[11]

Appelbaum followed with a similar article detailing sports vision testing with the Nike Sensory Station, and training improvement with an organized sports vision training treatment program including stroboscopic training, again showing statistically significant improvement.[12] In Appelbaum's 2020 article,[13] An Early Review of stroboscopic visual training: insights, challenges, and accomplishments to guide future studies, he notes that foveation (central visual processing) has improved with SVT.

Again, the visual deprivation brought on by diminished visual information draws the subject's

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visual attention to their central vision, similar to what out-of-balance disruption does to vision. Working through this in SVT is now beginning to show measurable improvements in improved test results and, more importantly, in on field/court/pitch performance.

Lastly, in a 2020 study entitled, *The effect of stroboscopic visual training on eye–hand coordination,* Ellison et al noted using SVT works to improve perceptual cue usage and visual search behaviors on performance. They write, *One way to train vision and attention for sport is ot practice and train in suboptimal environments to overload perceptual processes, making return to the performance setting seem easier.*[14]

CONCLUSION

Since I introduced strobe glasses into the sports vision space, there have been many well-designed research papers worldwide. SVT shows promise in visual attention, foveation, hand-eye coordination, and athletic performance. Researching saccadic omission and the relationship of the vestibular, visual fixation, optokinetic, balance, smooth pursuit movements, and vergence movements provides a significant opportunity for ongoing research. Are you looking to answer questions as to whether we can improve the saccadic latency before initiation of movement? Can a person quicken their saccadic speed, whereby the eyes reach their target more quickly? What about the accuracy of target acquisition? Saccadic eye movement studies have been ongoing since the 1970s, if not before. We know that as your reading improves, the number and magnitude of undershooting and overshooting diminishes. For reading, a little residual accuracy error can still allow for word recognition (through the perceptual skill known as visual closure). It stands to reason that with a moving target, especially a baseball, tennis ball, hockey puck, or shooting clay, one might not have as much room for error. SVT is a promising tool in the quest for understanding what limits can (and cannot) be reached in human visual performance.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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