PERSPECTIVE

A New Model for Sports and Performance Vision

Daniel Laby, MD
Sports and Performance Vision Center, State University of New York College of Optometry, New York, New York

David Kirschen, OD, PhD, FAAO
Southern California College of Optometry, Fullerton, California, Jules Stein Eye Institute, University of California, Los Angeles, California

EXECUTIVE SUMMARY

In an attempt to understand the role of vision in sport performance, two-dimension models for processing visual information are reviewed. Lacking the power to fully explain all aspects of vision that are required in sports, a multi-dimensional model is proposed as a way to appreciate, more fully, the role that each of the components of the visual system plays in capturing visual information, processing it and initiating a motor response based upon the processed visual information.

Correspondence regarding this article should be emailed to Daniel M. Laby MD, at drlaby@sportsvision.nyc.

Laby D, Kirschen D. Case Report: A new model for sports and performance vision. Vision Dev & Rehab 2018; 4(2):85-91.

Keywords: multidimensional model of sport vision performance, sports vision, two dimensional model of sports vision performance

Three separate, but integrated, components are proposed for this multi-dimensional model, the visual system, the visual information processing system, and the psychological processes that sub serve visual perception. These three systems work separately but in an integrative fashion with different weighting functions to produce the Go, No-Go decision needed to initiate a motor action.

The ability to see and then create an appropriate motor response is central to optimal sports performance. Essentially all sports require the participants to have open eyes and use their vision for success.[1] The ability to see the target, determine its motion whether being an opponent, a moving object, or the goal is required for optimal performance.[2]

How we achieve optimal performance, and what role and to what extent our visual systems participate in performance is yet an entirely different question. Many have attempted to describe and define the role of vision, leading to a motor response, in the past. unfortunately, though, these models have suffered due to being restricted to a two-dimensional, foreword/backward approach as opposed to considering a more physiologic multi-dimensional/multi-directional paradigm.

What do we mean by two-dimensional? A two-dimensional system has no depth, and implies a sequential start to finish approach, from left to right, with an additional pathway allowing for system feedback. This is the classical model described by Welford and Whiting (Figure 1)[2,3] as well as more recent models presented by Kirschen and Laby (Figure 2).[4] In the classical model by Welford,[5] sensory information is passed forward through a sequential series of three "mechanisms". The Perceptual mechanism, the Decision mechanism and the Effector mechanism. From the effector mechanism, signals are sent to the muscular system in order to create a motor action. Extrinsic as well as intrinsic feedback, including the application of prior experience

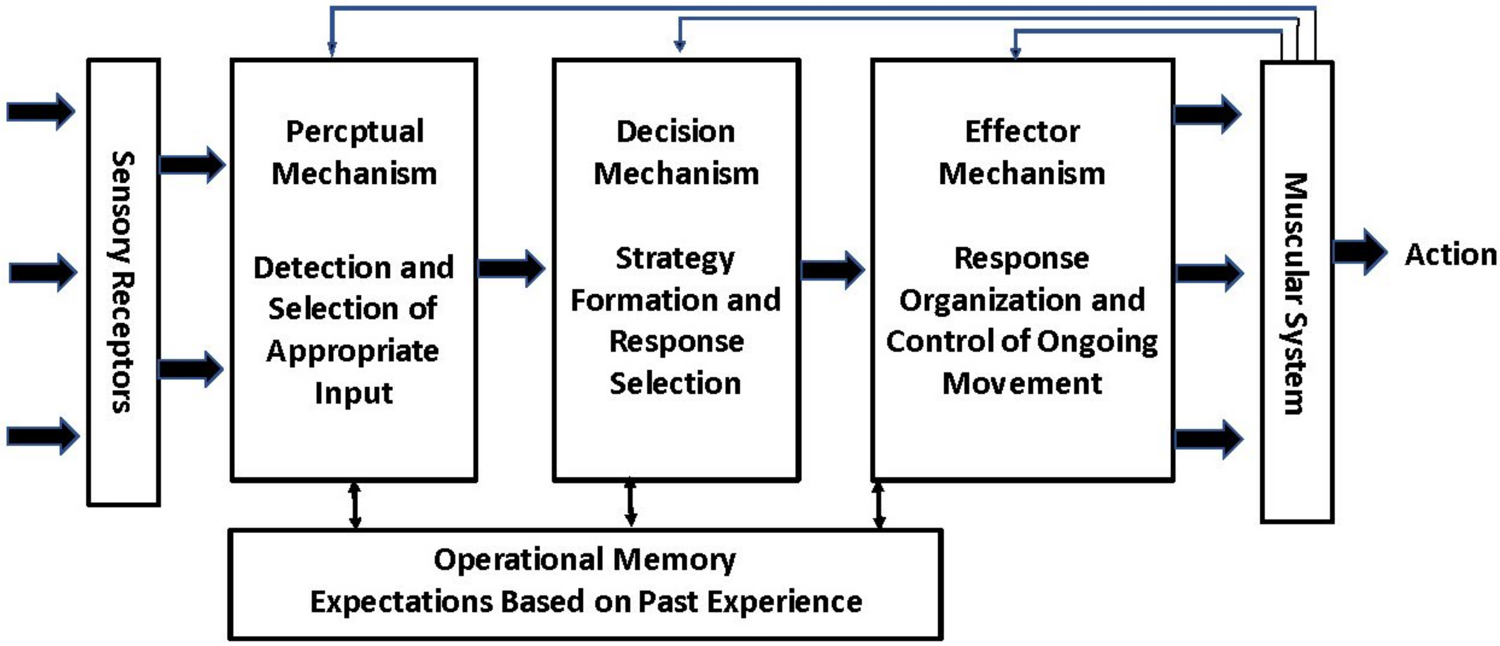

Figure 1

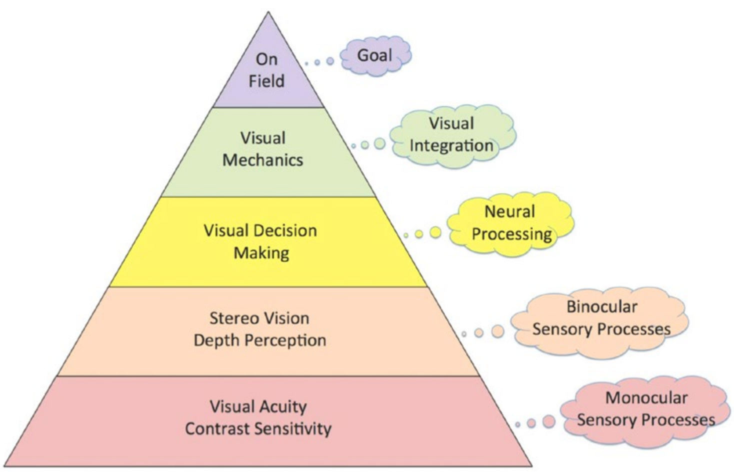

Figure 2

and memory, may alter, or temper, each step. In this model, a sequential approach is applied with basic sensory information moving from one mechanism to the next with no back propagation or internal integration of the central processing mechanisms. Although two dimensional, this model is nonetheless effective in describing the parts necessary to incorporate sensory information, in our case visual information, into a specific motor action based on that sensory information.

A more recent paradigm described by Kirschen and Laby (Figure 2)[4] presents a sports vision pyramid. Again, a sequential two-dimensional approach to understanding the integration of vision in sports performance is described. In this model, the concept of a pyramid is used in order to highlight the paradigm that in order to build a stable, long-lasting pyramid each level must be built on a solid preceding foundational level. Should one lower level be weak, or of less width in the case of a geometric pyramid, the pyramid will not be stable and will not function properly. In this model, dedicated to the visual system, the authors describe the basic monocular visual functions of visual acuity and contrast sensitivity as forming the pyramid base. Above, and wholly dependent on the preceding monocular abilities, is the binocular visual function of stereoscopic vision. Without optimal function of each monocular ability, binocular function cannot be optimal. The next level of the sports vision pyramid utilizes the now binocular visual input to make a "go" vs. "no-go" decision. Most all decision tasks in sports can be boiled down to a simple decision to interact or not interact with an event. In the case of interaction, an appropriate motor action must be commenced, and in the case of a no-go decision an inhibitory process must be used to prevent a previously contemplated motor action. This decision is only as reliable as the information supplied to it, highlighting the importance of the previous binocular and monocular levels of the pyramid. Lastly, sitting above the decision level of the sports vision pyramid is the motor effector level. Here, with a "go" decision, the previous visual information must be coordinated into a rapid, efficient, and precise motor action. Again, this motor action and its success will be directly related to the previous information provided by lower levels of the pyramid. With optimal function of each and every level below the apex of the pyramid, successful sports performance can be obtained.

Although the sports vision pyramid is a reasonable description of what is required, and in what sequence, for optimal sports performance – it remains, as noted with the Welford model, a two-dimensional (in this case in the vertical axis), bottom-up, sequential, approach to the role of vision in athletic performance.

Perhaps a different approach could shed more light on the role of vision in sports performance? An approach which takes into account more recent understandings[6] of both the physiology of the visual systems as well as the cognitive interactions between vision and other portions of the central nervous system, all designed to create the most accurate and timely motor responses required for elite sports performance.[7] An approach, different from the models discussed above, that incorporates both the bottom-up as well as the top-down flow of information, which ultimately leads to the initiation (or the inhibition) of a specific motor action, may be more useful in understanding the visual process of athletes.

This approach requires consideration beyond the classic two-dimensional, sequential approach presented above and requires a paradigm shift in our approach. This approach can be considered a three-dimensional or perhaps even a multi-dimensional understanding of the highly complex, and clearly not fully understood, workings of the human brain as it relates to visuo-motor performance.[8]

Some 50 years ago, at the beginning of the computer age, computers where considered only able to carry out a sequential series of steps, written as a "program". In fact, one of the initially highly popular computer languages, BASIC, required the use of line numbers which were executed in sequence, highlighting this very two-dimensional process. The benefit of the computer was in its ability to carry out these steps very quickly, often much faster than was consciously humanly possible, thus creating its benefit. Over the years, computers became faster and faster, and were able to carry out incredibly difficult, complex and often tedious tasks – but none were able to approach the creativity and performance of the human mind.

Recently, in the past several decades, computer scientists have worked to move beyond this two-dimension process and attempt to impart a form of intelligence on computer systems. Thus, the field of AI – artificial intelligence – was born. In AI, computers began to move from the two-dimensional performance of a sequential set of instructions to a more multi-dimensional ability to learn from experience, to adapt to a changing environment and even to, in some cases, write its own instruction program.

This multi-dimensional programming approach, initially intended to mimic or copy how the human mind works, can in fact be applied to how our mind works in terms of sports vision. Modern AI programming

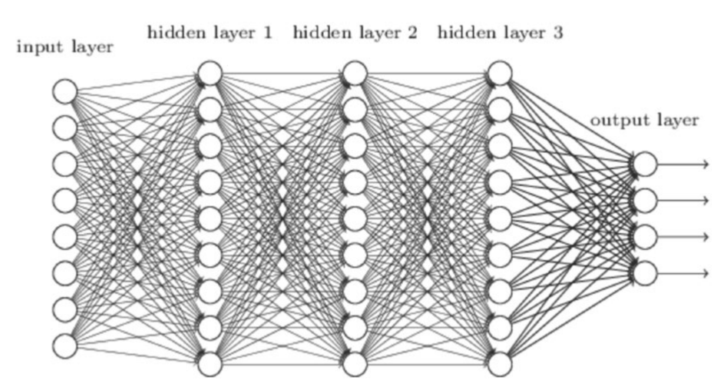

Figure 3: Reprinted with permission from Michael Nielson. neuralnetworksanddeeplearning.com

makes use of a neural network (Figure 3),[9] comprised of layers of discreet nodes, each of which is interconnected and dependent upon other nodes. The relationship between one node and another is often described as a "weighting" function and is continually adapted and "tweaked" based on experience. Additionally, the sum total of all the nodes is fed back to the early nodes on a constant and ongoing basis in order to continually optimize the performance of the neural network. Whether described simply as machine leaning or deep learning, the effect is the same, in real time, each stage of the process is continually adjusted and adapted to optimize the performance of the entire system. Additionally, although the system cannot work without some form of input or data, each node participates in forming the final output, albeit based upon the inter-node weighting system. Thus, data is fed forward, backwards, up, down and sideways, in real-time, and each node participates in the performance of the other network nodes to create an optimal total result. Most importantly though, neural networks can learn and become more efficient and faster in arriving at an appropriate response/answer. The earlier models discussed above (e.g. Welford) are static models and whether information is submitted 1 or 100 times, the models respond the same way each time. Neural networks, and certainly the human brain, are different in that they learn and improve with experience, guaranteeing that the first experience will be very different than the 100th time an athlete sees the same information. It is precisely this ability to learn and adapt which distinguishes the earlier models from our current understanding of relevant physiology.

In terms of visual performance, the artificial intelligence paradigm can be used to consider three separate networks (Figure 4), each contributing to form the sports vision paradigm. The first network is the visual system, the second network is the central processing

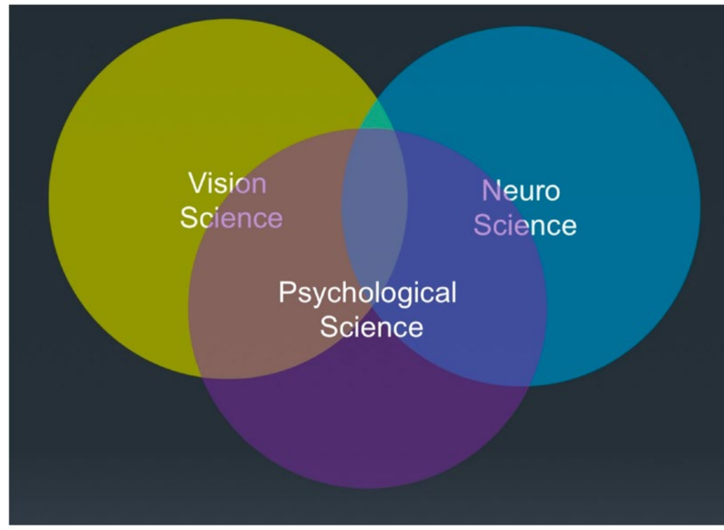

Figure 4

of visual information, while the third network brings into play the psychological aspects of performance including previous experience such as success and failure as well as the role of bias in our visually based decisions. Each network acts as an independent, multi-dimensional, essentially non-sequential process that interacts with each of its neighbors, with different weights depending on the particular circumstance, to produce the basic go/no-go decision and effect the motor action. Additionally, besides the ability to learn, this proposed paradigm includes the ability of the athlete to constantly adjust and shift attention from one area of their visual field to another; based on the multiple inputs originating in any of the areas contributing to overall function (e.g. prior experience, visual input, psychological aspects, etc.). Some authors[10-13] feel that this visual attention is actually guided by the matching of bottom-up sensory visual information with top-down expectations generated based upon experience, expectation, anticipation, and other factors all of which are constantly changing based upon moment to moment circumstances. Matching of what is expected with what is seen drives attention to elements of the visual field, representing another dimension of the proposed model.

The *visual system*, perhaps the most familiar of the three, is highly complex and is far from a sequential processing system. Although in an elementary understanding, light does enter the eye, is transformed into an electrical signal and is passed to the visual cortex where it is then presented to the higher brain functions for use. In reality, light is transformed at each level of the eye in a particular way, is adapted and massaged in the retina as it is changed from light energy to an electrical potential and is significantly processed by the higher visual areas particularly, but not limited to, the visual cortex.

By following a ray of light as it passes through the visual system, we can perhaps begin to understand this highly complex process. A ray of light that leaves a target, it being a pitched baseball or a hockey puck for example, first interacts with the eye at the level of the tear-air interface on the ocular surface. Depending on the integrity of this interface, which is in fact the portion of the eye with the greatest refractive effect, the light ray may be significantly affected and distorted. For example, subjects with dry eyes often experience blurred or reduced vision,[14] but a clinically dry eye is not required to produce a detrimental effect on the vision of an athlete. Even a nominally dry, or irregular, ocular surface can create optical aberrations which can affect visual ability – especially in athletes whose visual systems have been described to be far superior to that of the average non-athlete.

Light then passes through the cornea and lens, the classical refractive elements of the eye, where it is once again changed and exposed to additional aberrations and distortions.[15,16] By the time our rays of light reach the retina they are very different from how they left our sports target. In the retina, whose primary role is to change light to electrical potentials, a large amount of signal processing occurs. This processing has been fairly well described and understood and includes both vertical as well as horizontal processing in the retina to begin to create information that can be used in the decision-making process. Inherently, when information is processed it is transformed and changed. Although we have some understanding of what happens in the retina, we are less certain of why and how this transformation occurs and what dynamic factors can affect, or do affect, the result. Once processed, the signal moves posteriorly toward the occipital lobe, passing through additional structures that combine (optic chiasm) as well as separate (lateral geniculate nucleus – LGN) the signal into discreet purposes. In the LGN it is understood that there are discreet layers, each comprised of different forms of visual information, destined for different parts of the primary visual cortex. Interestingly, not all visual information leaving the retina ends up in the visual cortex of the occipital lobe. Branches of visual information have been identified to synapse directly with functionally higher levels of the brain, specifically in the areas responsible for motion detection, thus allowing an individual who is cortically visually blind to still perceive object motion.[17]

As is evident in this very simplified description of the basic visual system, light does not simply enter the eye and is then conveyed posteriorly, instead it is adapted, changed, analyzed, separated, and branched as the signal interacts with the other networks that comprise the central nervous system. Precisely how this visual network is constructed functionally and how each part interacts with the other parts still requires greater understanding, but what is clear is that it is highly complex, dynamic and interactive.

The second network that interacts with the visual system to produce the necessary motor response can be considered the *"neurological visual system."*[18] This network encompasses the processing of the visual signal which occurs after the visual cortex. Although comprised of many nodes, or centers, each is inter-related and contributes to the final action. From the dorsal visual stream which carries "when and where" visual information toward the parietal lobe to the ventral visual stream which carries "what" information towards the temporal lobe, each pathway is clearly not isolated and is affected along the way by other cognitive processes. These cognitive processes adapt and change the visual information based upon past, current and anticipated future visual experience. Additional areas such as the superior temporal sulcus which is particularly sensitive to motion and which receives visual input not only from the occipital cortex, but also from ocular fibers that progress directly to the higher brain levels via the optic tracts and the superior colliculi located below the thalamus in the midbrain; to the fusiform gyrus and the supplemental motor area which are critical in forming the go/no-go decision; to the superior colliculus which directs shifts in ocular gaze – all are inter related and dependent upon each other to create optimal function.

The final, equally important and integrated network are the psychological aspects of visual function and decision making. It has long been clear that two individuals can experience the same event but "see" completely different things. How our visual system "sees" is perhaps an area which will never be fully explained, but despite its complexity some themes are clearly evident. This network includes the effect of previous experience, expectations, emotion and situation on visual information to finally lead to the go/no-go decision necessary for a motor action to occur. It has been shown that athletes are 35% faster and 31% more accurate in decision making than non-athletes[19] likely due to more efficient and appropriate use of decision heuristics as described by many, including Kahnemann and Tversky.[20]

Kahnemann and Tversky spearheaded the field of decision making and highlight several areas that are relevant to sports and performance vision and can affect how we "see". For example, they noted that initial exposure to a stimulus can affect one's later appreciation and response to a same or similar stimulus, they described the "law of small numbers" in which the error in estimating the behavior of a large population from observation of the characteristics of a small population is described, they described the concept of "anchoring" whereby we are overly influenced by the partial exposure to a situation, overshadowing the complete exposure, and experience. They also noted that we are more sensitive to losses and will, when faced with a choice between a low probability of a loss vs. a good probability for a gain, choose to avoid the loss over a more likely gain.

For example, a batter facing a pitcher who hit a home run the first time they faced each other might rely on the small sample size and be overly confident in his assessment of the pitcher. Also, he may rely on how his teammates have batted against this pitcher as an indication of his chance for success. If the pitcher throws a pair of initial balls, the batter may really feel he will be able to hit a home run again – only to try and get out of the eventual 3 and 2 count, by taking the final pitch, not swinging and being called out on the third strike over the outside corner.

The batter in the example should have known better than to rely on his initial at-bat against this pitcher and its positive outcome. He should have known better than to rely on the small sample size of his previous at-bats with this pitcher. He should have realized that the performance of his teammates was a very small sample size and may not be reflective of this pitcher's abilities over time. And worst of all, he should have avoided being anchored to the idea that this pitcher has poor control and will throw four balls for a walk after the initial two balls thrown. These errors led to the eventual 3-2 count and his eventual strikeout.

All of these behaviors, assumptions, and prior experiences play a role in an athlete's decision making process based upon what they see and ultimately their ability to execute a proper motor action for success. Visual information is not simply propagated forward with minor impacts from feedback loops; instead vision is one piece of a complex puzzle of information which when taken as a whole, and properly weighted, is used to arrive at a decision to trigger a motor action. Memory, experience, expectations, bias, to name a few, in addition to vision are all merged together prior to the actual decision. In addition, and most importantly, the result of the decision is used to update the neural network and is available for future use in hopefully making the next required decision that much better.

None of these paradigms are correct, while at the same time they are all correct. Paradigms are simply an attempt to explain nature's function. In some cases, the two-dimensional paradigm describing sports performance may be sufficient, while in other cases even the most complex, multidimensional model may not be sufficient to describe what is happening. As sports vision specialists it is our role to try and explain what we see in athletic competition, and devise ways to correct or enhance visual function in the hopes that it will lead to improved performance. If this can be explained with "models" or "paradigms" then all the better, for in order to create a plan of action, understanding of function is imperative.

REFERENCES

1. KnudsonD, Kluka DA. The impact of vision and vision training in sport performance. Journal of Physical Education, Recreation & Dance. 1997;68(4):17-24.
2. Appelbaum LG, Erickson G. Sports vision training: A review of the state-of-the-art in digital training techniques. International Review of Sport and Exercise Psychology. Published online Dec 21, 2016. http://bit.ly/2yePqQi
3. Erickson G. Sports Vision: Vision Care for the Enhancement of Sports Performance. St. Louis: Butterworth Heinemann 2007.
4. Kirschen DG, Laby DL. The role of sports vision in eye care today. Eye Contact Lens. 2011;37(3):127-30.
5. Welford AT. The measurement of sensory-motor performance: survey and reappraisal of twelve years'progress. Ergonomics. 1960;3(3):189-230.
6. Miller BT, Clapp WC. From Vision to Decision: The Role of Visual Attention in Elite Sports Performance. Eye & Contact Lens. 2011;37(3):131-9.
7. Heppe H, Kohler A, Fleddermann M-T, Zentgraf K. The relationship between expertise in sports, visuospatial, and basic cognitive skills. Frontiers in psychology. 2016;7:904.
8. Tozzi A, Peters JF. Towards a fourth spatial dimension of brain activity. Cognitive Neurodynamics. 2016;10(3):189-99.
9. Lipton ZC, Berkowitz J, Elkan C. A critical review of recurrent neural networks for sequence learning. arXiv preprint arXiv:1506.00019, 2015. http://bit.ly/2JHb00N
10. Wolfe JM, Horowitz TS. What Attributes Guide the Deployment of Visual Attention and How Do They Do It? Nat Rev Neurosci. 2004;5:495-501.
11. Druzgal TJ, D'Esposito M. A Neural Network Reflecting 266 Decisions About Human Faces. Neuron. 2001;32:947-955.
12. Womelsdorf T, Fries P. The Role of Neuronal Synchronization in Selective Attention. Curr Opin Neurobiol. 2007;17:154-60.
13. Gazzaley A, Cooney JW, McEvoy K, et al. Top-down Enhancement and Suppression of the Magnitude and Speed of Neural Activity. J Cogn Neurosci. 2005;17:505-17.
14. Benítez-del-Castillo J, Labetoulle M, Baudouin C, Rolando M, Akova YA, Aragona P, et al. Visual acuity and quality of life in dry eye disease: Proceedings of the OCEAN group meeting. The ocular surface. 2017;15(2):169-78.
15. Kirschen DG, Laby DM, Kirschen MP, Applegate R, Thibos LN. Optical aberrations in professional baseball players. J Cataract Refract Surg. 2010;36(3):396-401.
16. Laby DM, Kirschen DG. The Refractive Error of Professional Baseball Players. Optom Vis Sci. 2017;94(5):564-73.
17. Lee AG, Morgan ML, Palau AEB, Mai CK, Chen Y, Soeken T, et al. Anatomy of the Optic Nerve and Visual Pathway. Nerves and Nerve Injuries: Elsevier; 2015. p. 277-303.
18. Whishaw IQ. The mystery of the motor cortex. Brain and Behaviour: Revisiting the Classic Studies. 2016:19.
19. Mann DT, Williams AM, Ward P, Janelle CM. Perceptual-cognitive expertise in sport: A meta-analysis. Journal of Sport and Exercise Psychology. 2007;29(4):457-78.
20. Lewis M. The undoing project: A friendship that changed our minds: WW Norton & Company; 2016.

AUTHOR BIOGRAPHY:

Daniel Laby, MD
New York, New York

Dr. Laby has been trained in Ophthalmology and specializes in Sports Vision. He has served as staff ophthalmologist for several professional sports teams in MLB, NHL, NBA as well as the US Olympic team. He is honored to have been a part of 5 World Series Championship teams and an American League Championship team. Dr. Laby is board certified by the American Board of Ophthalmology and is a member of the American College of Sports Medicine. He has authored many journal articles (40+), textbook chapters (4), and is the co-author of Dictionary of Ophthalmology. Recently, Dr. Laby was honored with the Eagle award by American Optometric Association's Sports Vision section.