Vision Performance Evaluation for Athletes

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Hierarchy of Function

- Imagine a pyramid, where a base is used upon which to build higher levels of function
- A strong base allows for strong upper levels
- Basic visual function can be divided into Visual Acuity/Contrast Sensitivity & Stereo
- All other functions will suffer if these are not maximized

Courtesies of Dan Laby & David Kirschen

Vision Mechanics

- The integration of physical visual abilities with higher cortical levels of information processing
- Can be considered the use of basic visual functions to achieve a specific physical task such as:
  - Visual Processing Speed and Span
  - Peripheral and Central Eye-Hand/Foot Reaction
  - Visual Anticipation

Welford Information Processing Model

PERCEPTUAL MECHANISM

- Visual Acuity
- Contrast Sensitivity
- Dynamic Visual Acuity
- Ocular Alignment
- Stereopsis
- Accommodative Function
- Vergence Function
- Oculomotor Function
- Peripheral Vision

Visual Acuity

- Optotypes
  - Snellen-type letters
  - Landolt rings
  - Computerized (M&S)
- Ideal Testing Strategy
  - Starting acuity level (20/60 size)
  - Ending acuity level (past limit of resolution)
  - 4-choice double error staircase method
  - Standard interactive method
Visual Acuity

- Most studies since 1924 have found better static VA in athletes compared to nonathletes.
- Several studies have found a mean acuity of 20/15 or better; consider the “minimal desired visual acuity for a competitive athlete.”
- However, it is not uncommon to find some athletes performing at a high level despite having reduced VA’s.
  - Consider the task demands

Visual Acuity of Professional Baseball Players


Both systems:
- Shift from Analog to Digital
- Standardized protocols for assessment
- Athlete databases for patient comparison
- Nike system now available from Senaptec

Visual Clarity

- 4-position Landolt Rings (c’s)
- Starts above threshold (20/50) and decreases in steps until below threshold (max VA = 20/8)
- Repeated trials in double-staircase algorithm to determine threshold acuity
- Referrals: Red (Required) & Yellow Cards

Refraction

- Determined with auto-refraction, retinoscopy and ultimately a careful balanced refraction
- Care devoted to accurately determine spherical and cylindrical refractive errors with emphasis on power and axis determination
- Cycloplegic refraction may be needed in hyperopes
- As long as refractive error is carefully corrected, it is unlikely to create horizontal phoria
Refractive Errors

- Junior Olympics study
  - 31% wore eye wear routinely
  - 13% wore contact lenses to school
  - Unfortunately – less than 1% wore protective eye wear
  
  *Beckerman SA, Hitzeman S. The ocular and visual characteristics of an athletic population. Optometry 72:498, 2001*

- Requirement for refractive correction should not deter athletic participation – in fact, many professional athletes welcome the correction of small refractive errors as an advantage in sport.

Contrast Sensitivity

- Test type
  - Gratings vs. Bulls Eye
  - Sine wave vs. square wave
  - With or without glare interference

- Testing System
  - Fixed presentation (CSV, VCTS Systems)
  - Random presentation (M&S ProSports; Sensory Station)
  - Must test to threshold
  - Must control lighting and calibration
  - 3+ choice double staircase algorithm

Contrast Sensitivity

- Concentric ring targets at far (16 ft.)
- Rings have neutral effect on astigmatism axis
- Rings are presented in 1 of 4 circles
- Measures sinusoidal CSF at 6 and 18 c/d
- Measures contrast ratio down to 0.4%
- Staircase algorithm to determine binocular threshold
- Athlete responses via iPod touch

Contrast Sensitivity

- Consider appropriate test gratings for sport – blue/white (sky) or red/white (seams) for baseball.
- Consider effect of tints on CSF – different tints for different playing conditions
- Consider assessing the effect of tints on CSF in natural light
- Incorrect tints (sunglasses) and some colored contact lenses may decrease an athlete’s CSF

Contrast Sensitivity

- The general results suggest elevated CSF across all spatial frequencies for athletes.
  - Exceeds norms published by the Vistech company for a “normal” population
  - Reduced CS may contribute to performance inconsistency due to widely variable contrast conditions present in most sports

- It has been demonstrated that contact lenses can degrade CSF if the lenses are not optimal
Dynamic Testing

- Can be used for Visual acuity, Stereo acuity and contrast sensitivity testing
- Cannot predict based on typical static vision testing in office
- Believed by some to be a more true predictor of visual function during athletic competition
- No standard agreement on definition or methods to test:
  - Does the target move (horiz/vert/rotary/z-axis)?
  - Does the optotype change size dynamically?
  - Does the athlete move?

DVA Methods?

Target Capture (Sensory Station)

- 4-position Landolt ring target presented at far (16’)
- Ring size is based on VA threshold
  - 0.1 log unit above threshold
- Ring presented in 1 of 4 corners of monitor
  - angular distance ~6.1°
- Athlete responds via iPod touch with the direction of the Landolt ring
- Exposure duration for ring starts at 500ms & decreases with correct responses
- Staircase algorithm to determine threshold exposure duration

Target Capture

Right Eye

- Assesses DVA with gaze tracking:
  - Head moving
  - Object moving and head still
  - Both head and object moving

Literature Support

- Variability in measurement parameters has created significant difficulty in determining performance characteristics.
- Most studies found better DVA in athletes compared to nonathletes
  - Typically better in goal- and wicket-keepers, baseball/cricket batsmen and tennis players
Ocular Alignment

- Alignment needed for normal binocular vision – stereopsis
- Can be evaluated with any of a series of tests (cover tests, Maddox rod, fixation disparity tests)
  - Assess in all relevant gaze positions
- Eye care provider must be aware of benefits and complications of each test
- Consider effect of phoria on binocular function – few athletes have constant tropic misalignments

Literature Support

- Early studies found lower amounts of heterophoria in athletes (especially at far), but more recent studies have not confirmed these findings.
- Some suggest that measurement of fixation disparity may be a better assessment of the accuracy and stability of eye alignment.
  - Method?

Stereo Acuity

- Test Type
  - Contour
  - Random Dot
  - Howard-Dolman apparatus
- Testing System
  - Testing at Far (e.g. 20 feet) vs. Near
  - Automated testing paradigm allowing for randomization and testing to threshold
    - (M&S ProSports; Sensory Station)
  - Effect of timing on stereo acuity result

Depth Perception

- 4 ring targets presented at far (16 ft.)
- Disparity demands via wireless liquid crystal shutters
- Measures stereopsis between 237 and 12 arc sec
- Staircase algorithm to determine threshold
- Average response speed at threshold calculated
- Athlete responses via iPod touch
- Performed in primary, right and left gaze positions
- Referrals: Yellow Cards

Literature Support

- Studies have demonstrated that binocular vision can improve performance on certain tasks compared to one-eyed performance.
- Research comparing static stereopsis performance has had mixed results with athletes, some differences due to differences in testing procedures used.

Dynamic Stereoacuity

- It has been suggested that the lack of correlation between depth perception and athletic performance is due to the static nature of the testing.
- Dynamic stereopsis assessment procedures have been suggested to discriminate differential performance relating to sports.
Ocular Dominance

- Controversial topic
- Many tests for dominance exist, with poor agreement between tests as to dominant eye
- Many factors can influence result of ocular dominance test (handedness, shoulder/arm abnormalities, etc.)
- Don Tieg (1980) suggested that more players with crossed eye-hand dominance (using a pointing test) may be beneficial to team batting averages

Ocular Dominance

- Classically considered only either Right or Left by the pointing test
- New thoughts allow for Intermediate forms as well as Central Eye Dominance

Ocular Dominance

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<tr>
<th>Batting av.</th>
<th>ERA</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>0.271</td>
<td>3.34</td>
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<tr>
<td>Major</td>
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<td></td>
</tr>
<tr>
<td>Crossed</td>
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<td>3.56</td>
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<tr>
<td>Minor</td>
<td>0.20</td>
<td>-0.66</td>
</tr>
<tr>
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<td>0.270</td>
<td>4.20</td>
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Ocular Dominance

- In the majority of sporting events – players will need to use both eyes together for maximal function
  - Exception: Sports that require sighting with one eye (shooting)
  - Otherwise – we should work towards maximal function in each eye (monocular function) and maximal binocular function to maximize on-field performance

Ocular Dominance

- Drs Laby and Kirschen compared the relationship between dominance pattern (same or crossed) and baseball performance and found no effect on performance

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Ocular Dominance

- There have been many theories concerning the advantages/disadvantages of crossed eye and hand dominance in sports performance.
- Coren & Porac found that the dominant eye processed visual information ~14msec faster than the nondominant eye, fueling speculations.

Ocular Dominance

- Useful to test when visual system uses the accommodative system in a performance task
- Challenge for the ECP
  - Determine which performance tasks involve accommodation
  - Which aspects of accommodative function are the most critical in performance

Literature Support

- There have been many theories concerning the advantages/disadvantages of crossed eye and hand dominance in sports performance.
- Coren & Porac found that the dominant eye processed visual information ~14msec faster than the nondominant eye, fueling speculations.
Accommodative Function

- Accommodative Facility
  - NPA is probably irrelevant in sports
  - Step accommodation ability is probably much more important than sliding accommodative ability
  - Jump demands from distance to near and visa versa are probably the most relevant because both vergence and accommodation are active

Vergence Function

- Useful to test when the visual system can use the vergence system in a performance task
- Challenge for the ECP
  - Determine which performance tasks involve vergence
  - Which aspects of vergence are the most critical to performance

Vergence Function

- Vergence Facility
  - NPC may be irrelevant
  - Step vergence ability is probably more important than sliding vergence ability
  - Jump demands from distance to near and visa versa are probably the most relevant because both vergence and accommodation are active
  - Vergence may be used in tracking moving sports objects (e.g. fly ball in outfield)

Accommodation & Vergence

- Haynes Distance Rock Test
  - Assesses speed and accuracy of accommodative/vergence facility
  - No control for binocularity/suppression
  - Published normative data for elite-level athletes; no comparative studies

Near-Far Quickness

- 4-position Landolt ring target presented at far (16 ft.), and near (on iPod touch)
- Far ring size is based on VA threshold
  - 0.1 log unit above threshold
- Near ring size is 20/80
- Rings presented alternately at each distance
- Number of correct responses in 30 sec. determines performance score
- Athlete responses via iPod touch

Accommodation & Vergence

- WARNING: Time factors for accommodation & vergence response (latency ~600ms)
Oculomotor Function

Useful to test when the visual system can use the oculomotor system in a performance task

Challenge for the ECP

- Determine which performance tasks involve oculomotor tasks
- Which aspects of oculomotor functions are the most critical
  - Fixations (The Quiet Eye™)

Literature Support

- Studies have found that athletes do NOT have shorter latencies for initiating pursuit or saccadic eye movements.
- However, if the target trajectory is predictable, the latency period can be reduced through a learning effect
  - Example: initiating the correct pursuit eye movement to track a baseball pitch
- Studies comparing the speed of pursuit eye movements in athletes and nonathletes have found mixed results.

The Quiet Eye™

- Mobile Eye Tracking
- Right Eye
  - “Ball Tracking”
  - “Inhibition”

Oculomotor Function

Which aspects of oculomotor functions are the most critical

- Saccades
  - Latency
  - Accuracy
- Pursuits
  - Latency
  - Accuracy

Qualitative

- Observe eye movements when the athlete is fixating, making saccades between 2 objects or smoothly pursuing a target
  - Look for speed and accuracy, over and under-shoots

Quantitative

- Eye movement recordings – ReadAlyzer
- Mobile Eye Tracking system

Literature Support

- Qualitatively better?
  - Studies that assessed the subjective quality of eye movements found better skills in athletes.
  - The subjectivity of the assessment methods used in these studies brings the reliability and validity of these findings into question.
Peripheral Vision

- Extent of Visual Field
- Form Recognition in Periphery
- Peripheral Awareness/Reaction

Literature Support

- Extent of Visual Field
  - Study results indicate that athletes have a larger extent of horizontal and vertical visual fields than nonathletes.
  - However, it was NOT found to be a sensitive discriminator of skill level within a sports population (Varsity vs. JV collegiate football)

Literature Support

- Form Recognition in Periphery
  - Study results indicate that athletes have better form recognition at more peripheral locations than nonathletes.
- Peripheral Awareness/Reaction
  - Only normative data have been published for measurements of peripheral awareness/reaction using the Wayne P.A.T.T. in athletes.

Welford Information Processing Model

决策机制

- 决定性机制
  - 速度的识别
  - 视觉注意力 / 可视化
  - 多对象跟踪

速度的识别

- 挑战对于 ECP
  - 决定哪些表现任务涉及速度的识别
  - 决定哪些测试最好地评估速度的识别
  - 决定在表现任务中哪个指标最好地评估训练改进
- Tachistoscope 呈现
- 感觉训练系统
- 感官站

Dreary Jr, Mitchell H (1986)
Isaacs LD, Finch AE (1983)
Nettleton B (1986)
### Perception Span

- Grid pattern of circles presented at arm’s length
- Pattern of blue-green dots is presented when a white central fixation dot disappears
- Blue-green dot pattern exposed for 100ms
- Athlete touches screen to re-create the pattern following exposure
- Largest grid pattern is <20° of central visual field
- Grids and dot patterns pre-set to maintain standardization

**Example Levels:**
- First two levels have 6 circles in the grid pattern with 2 and 3 dots
- Next 5 levels have 18 circles with 3 to 7 dots
- Last 4 levels have 30 circles with 7 to 10 dots
- Passing score for each level > 75%
- If athlete doesn’t achieve a passing score on a level, that level is repeated
- Score = cumulative number of correct responses; missed responses and extra guesses are subtracted from the cumulative score
- Maximum score = 64

### Literature Support

- There have been mixed results when comparing speed and span of recognition in athletes to nonathletes (speed is better; span is the same).
- The use of number sequences for recall may be the confounding factor, and this may be overcome by the use of more ergonomically appropriate targets (sport-specific; spatial info).

### Inspection Time

- **IT** is the psychophysical measurement of visual processing time, with shorter inspection times allowing accurate decisions to be made from shorter stimulus durations.
- Most studies have found that experienced athletes can evaluate relevant visual information more rapidly than inexperienced observers.

### Visual Attention Visualization/Imagery

- Arguably a critical factor in athletic performance
- No method available to assess these abilities with reliability and validity
- No method to assess on-field performance
  - Mobile Eye Tracking may provide some insight
- No published studies comparing athletes to nonathletes, or elite athletes to near-elite athletes

### Multiple Object Tracking

- Tracking objects as they move through space – targets and non-targets
- Tracking teammates and opponents
- Research....
NeuroTracker

- Research shows it can discriminate high-level from lower-level athletes, and that a brief training regimen with the program can produce improvements in sports-related ability
- Performance has been correlated with actual game performance in professional basketball players, and that training with this program can selectively transfer to improved small-sided game performance in university-level soccer players (Mangine et al., 2014; Romain, Guldner, & Faubert, 2016).

Multiple Object Tracking

- Pairs of circles revolve around each other
- One is identified as target before it moves
- Rotation reverses at random points
- Start with 2 pairs and go up to 4 pairs
- Then speed is adjusted in staircase algorithm to find threshold
- Difficulty is controlled through consistent spacing – speed differentiates performance

Welford Information Processing Model

- Sensory Receptors
  - Perceptual Mechanism
    - Detection and Selection of Appropriate Inputs
  - Decision Mechanism
    - Strategy Formation and Response Selection
  - Effecter Mechanism
    - Response Organization and Control of Ongoing Movement
- Operational Memory
  - Expectation Based on Past Experience

EFFECTOR MECHANISM

- Visual Motor Reaction/Response
- Vision & Balance
- Peripheral Responsiveness
- Coincidence-Anticipation

Visual-Motor Reaction Time

- Useful to test in sports requiring quick motor reactions to visual information
  - Central vision vs peripheral vision
- Challenges for the ECP
  - Determine which performance tasks involve visual-motor reaction time
  - Determine which tests best evaluates visual-motor reaction time
  - Determine which metric within the performance task is best to evaluate improvement with training

Possible testing equipment (w/quantification)

- Simple reaction time
  - Visual stimulus is presented at a random time and a motor action is required (e.g., a button push)
  - Can measure reaction & response times
- Choice reaction time
  - A stimulus is illuminated in a random position
Reaction Time

- Five trials are conducted to calculate average reaction and response times
- Reaction time is measured as the elapsed time between onset of the test annulus & release of the control annulus
- Response time is measured as the elapsed time between onset and touching of the test annulus

Visual-Motor Reaction Time

- For a given sport, determine which reaction time is most important and determine which performance modality is most important
  - eye-hand
  - eye-foot
  - balance response

Literature Support

- Simple eye-foot visual-motor reaction time studies have found faster RT’s in athletes in various sports, and it was a good discriminator of expertise level.

RightEye

- Simple Reaction Time
- Choice Reaction Time
- Discriminate Reaction Time

Literature Support

- Motor Response Time
  - Simple motor response times have been demonstrated to be faster in athletes than nonathletes.
- Visual-Motor Reaction Time
  - Simple visual-motor reaction time studies have had mixed results.
    - Several studies found faster RT’s in athletes in various sports, and it was a good discriminator of expertise level.
    - Other studies have not found this correlation

Literature Support

- Eye-Body Reaction/Response
  - Only normative data have been published for measurements of eye-body reaction/response speed using the Wayne Balance Board in athletes
The Quick Board

Peripheral Eye-Hand Response

- Useful to test when the visual system must direct a choice motor response to peripheral information
- Challenges for the ECP
  - Determine which performance tasks involve peripheral eye-hand response
  - Determine which tests best evaluates peripheral eye-hand response
  - Determine which metric within the performance task is best to evaluate improvement with training

Peripheral Eye-Hand Response

- Possible testing equipment (with quantification)
  - SVT (Australia)
  - Binovi Touch
  - Reflexion Edge

Peripheral Eye-Hand Response

- Possible testing equipment (with quantification)
  - Vision Coach
  - Sanet Vision Integrator
  - Dynavision

Peripheral Eye-Hand Response

- Possible testing equipment
  - Vision Coach
  - Sanet Vision Integrator
  - Dynavision

Eye-Hand Coordination

- A blue-green dot is presented in one circle at a time until it is touched
- When dot is touched, a subsequent dot is presented in a random location – athlete-paced
- Sequence of 96 dots is pseudo-randomized to maintain equivalent spatial distribution
- Score is the total time to touch all 96 dots
GO/NO GO
- Dot stimulus is either blue-green or red
  - Color parameters/saturation OK for color deficiency
  - If dot is blue-green, the athlete is directed to touch it as quickly as possible
  - If dot is red, the athlete is instructed not to touch it
- Dots appear at random locations for 450 msec
- 96 total dots presented (64 blue-green, 32 red) in a pseudo-randomized pattern
- Points awarded for touching a blue-green dot within the 450ms display time
- Points subtracted for touching red dots

Literature Support
- Using different evaluation methods and equipment, the results of eye-hand coordination in athletes has been demonstrated to be better than nonathletes in most studies
- “Reaction” vs. “Proaction” testing
- Light Levels

Visual Coincidence–Anticipation
- Useful to test when the visual system can anticipate the arrival of an object
- Challenge for the ECP
  - Determine which performance tasks involve anticipation skills
  - Determine which tests best evaluate anticipation skills
  - Determine which metric within the performance task is best to evaluate improvement with training

Literature Support
- Performance on the Bassin Anticipation Timer did not correlate with batting performance in baseball or softball.
- Timing accuracy was found to improve with increasing target velocity, decreasing range of movement, and length of runway.

Visual Coincidence–Anticipation
- Possible testing equipment (w/quantification)
  - Reaction time testing equipment modified to make the task predictive rather than random
  - The metric for performance would be a decrease in the reaction time for the task

Ocular Health Procedures
Generating a Visual Performance Profile

• M&S Technologies Sports Vision Performance
• Senaptec Sensory Station (formerly Nike)
• RightEye Performance Vision

ATHLETE PROFILE (Senaptec)

ATHLETE PROFILE (RightEye)

Reliability

• 3rd party university research
• N = 161 subjects
• Subjects evaluated twice one week apart
• No significant change between sessions = reliability
• Expected learned effects on 3 assessments
• Study showed reliability of the Sensory Station evaluation
• Optometry 2011; 82: 528-42

Organizing a Testing Battery

• The performance pyramid is a good approach to organizing which topics need to be considered in which order
• Each of the vision functions could be placed at the appropriate position on the pyramid

Organizing a Testing Battery

• The test battery needs to assess the perceptual mechanism elements that cut across most sports
  ▪ Acuity
  ▪ Contrast sensitivity
  ▪ Refraction
  ▪ Ocular alignment
  ▪ Depth Perception (stereopsis)
Organizing a Testing Battery

- The remainder of the test battery will be determined by the demands of the sport
  - Accommodation and Vergence
  - Oculomotor function
  - Reaction time related issues (Central vision)
  - Peripheral Reaction/Response
  - Coincidence-Anticipation
  - Other areas specific to sport demands

Organizing a Testing Battery

- Determination of "Essential" Skills
- Determination of "Beneficial" Skills
- Elimination of Superfluous Testing
- Establishment of Sport-Specific Evaluations
  - Modify testing battery based on position

DISCUSSION

Reference: