Study of Protective Eyewear for Handball

Principal Investigators

Benjamin Schmid

David Steinberg

Consultants

Karl Citek, MS, OD, PhD

Professor Fraser Horn, O.D., Ph.D.: Chairman, Sports Vision Council of the American Optometric Association.

Jeff Kastner, Videographer

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The purpose of this study was to test the efficacy of several common types of protective eyewear used for the sport of handball. The laboratory at Pacific University's School of Optometry, Forest Grove, Oregon campus was the site for the study. The lab offers the basic testing apparatus, tools and equipment, and several professors of optometry to provide expert opinion, oversight, comments and feedback to the experimental design and testing process.

Background

Eye injuries in sports are nearly always the result of blunt force trauma[1] to the globe and/or the surrounding soft tissue and orbital bones.[2] Effective eye protection attempts to prevent and/or mitigate such trauma, particularly to the globe, because of the danger of partial or full vision loss. In handball, globe trauma can result from direct contact of the ball, dislodged eyewear, pieces of broken eyewear and/or bone fragment projectiles, pressure transferred from the surrounding orbital tissues to the globe, or any combination of these. It must also be recognized that injuries to the surrounding soft tissue and bones can also affect vision with or without the presence of globe trauma, e.g. muscles controlling eye movement.[3] Indeed, one study showed the orbital floor bone could fracture under a mean energy of just 68-78 millijoules[4] of energy (a handball with a velocity of 50 mph carries 15.61 joules).

Research over the past few decades has compiled myriad studies using improvements in experimental design and advancements in technology. Mathematical models have been constructed that correlate well with test results showing a definitive relationship between risk of eye injury and measurable variables such as kinetic energy.[5] Our testing lies within this context. The investigators' research of published studies on eye injuries and protective eyewear for handball found

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[1] http://vtechworks.lib.vt.edu/bitstream/handle/10919/23814/Alphonse%202.pdf?sequence=1

[2] http://www.eyecalcs.com/DWAN/pages/v5/v5c045.html

[3] http://www.aao.org/publications/eyenet/200711/trauma.cfm

[4] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1298255/

[5] http://omicsonline.org/homeomorphic-model-of-the-effect-of-impact-trauma-on-the-human-eye-jcsb.1000317.pdf

scant and/or very old information, most contained within the broader research of other sports[6] . The one such study found specifically for handball only tested lensless eyewear[7,8] and was done in 1989.

To be effective, eyewear must be able to a) prevent direct ball contact with the globe, b) lessen and disperse the impact energy, c) remain intact and in place, d) fit comfortably, and d) minimize view obstruction.

The American Society for Testing and Materials (ASTM) wrote the protective eyewear standard F803 for specific sports. This standard, unfortunately, just references handball eyewear to the standard set for squash.[9] There are major differences in the basic physics between handball and squash when this standard is applied, e.g. the momentum of the 62 gram Red21 handball is over two and half times greater than the 24 gram squash ball. It is quite obvious to the principal investigators (and any student of physics) that the standard set for squash is not applicable to handball. Moreover, the ASTM does not conduct any testing; their standard outlines a specific testing procedure and criteria for passing it, leaving these responsibilities to the eyewear manufacturer. In short, the ASTM F803 standard has little applicability to handball eyewear. In contrast, the American National Standards Institute

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[6] http://www.eyecalcs.com/DWAN/pages/v5/v5c045.html

[7] http://articles.chicagotribune.com/1989-01-11/entertainment/8902240509_1_eye-injuries-american-amateur-racquetball-association-handball

[8] http://coloradohandball.com/main/Portals/0/Instructionals/oegft/Open%20(Lensless)%20Eye%20Guards%20Fail%20Testing.pdf

[9] ASTM F803, section 11.1.1.3, 2014: "When tested in accordance with Section 11, protectors which pass with the squash ball will pass also for badminton, handball..."

(ANSI) does not even write standards for sports eyewear; ANSI Z87 is written for occupational eye and face protection.[10] The sport of handball is, for the most part, on its own when it comes to eye protection.

Study Design and Details

This study simulated how sample eyewear products react to being struck by a handball and interprets observed effects on eye anatomy using data obtained from high speed video and a force measuring system. There are numerous variables to consider testing in a dynamic sport like handball. The investigators chose three to control: launch velocity, impact angle, and ball type. Three "shots" are done for each variable while collecting data from the video and force measurement equipment for each eyewear model.

In handball, the risk for globe injury from indirect impact is higher than direct impact for two reasons: the facial area, i.e. temple, nose bridge, where forces can be transmitted to the globe, is larger than the eye socket, and player positioning, i.e. the exposed player is most often looking back from an angle. The design of this study to include indirect impacts was initiated because of recent injuries of this nature that caused permanent vision loss. Interestingly, side and angled impact studies are noticeably absent from the body of research though this mechanism of injury and associated trauma is well documented.

The testing equipment consists of a Plexiglas enclosure containing the standard Canadian head-form for the

[10] http://www.lexeye.com/UserFiles/The-Mech-and-Prev-of-Sports-Eye-Injuries.pdf

average adult male and fixed on an adjustable mount. The ball is launched through an aperture in the Plexiglas from a Juggs gun over a light sensitive chronograph to measure velocity. Data from each impact is collected from two sources: an ultra high speed camera and a force sensor system. The camera is the Phantom V711 rented from Vision Research[11], the manufacturer. It is configured to operate at 20,000 frames per second using a 50mm lens and mounted approximately one foot from the manikin with an essential field of view of about six square inches perpendicular to the trajectory of the ball. The sensor unit is the Tekscan multi-handle high speed ELF system[12] with three thin film transducers connected via three USB ports to a Windows based computer. The ELF software can record up to 6000 force readings per second with an upper limit of 1000 pounds for each transducer. The transducers are mounted on the manikin under the eyewear on the inside nose bridge, the temple and on the eye.

The following parameters chosen for the study are: launch velocities of 50mph, 65mph and 80mph, and impact angles with the manikin of 0 degrees (frontal impact), 90 degrees (side impact) and 115 degrees (angled impact). The vast majority of adult players routinely hit the Red21 ball at 50mph. All handball specifications are available on the United States Handball Association's (USHA) web site.[13] Eyewear that fails on any shot will be deemed unsafe per the ASTM F803 standard and no further testing will be done on that model.

[11] http://www.visionresearch.com/Products/High-Speed-Cameras/v711

[12] http://www.tekscan.com/store/elf-systems/high-speed-elf-system.html

[13] http://www.ushandball.org

Tested Eyewear Models

Four commercially available eyewear models were tested, two sold by the United States Handball Association, one sold by Edtl Handball[14] and the other by O'Neills in Ireland.[15] The USHA models are the Blacknight Turbo and Racket-Specs, both manufactured by Unique Sports Inc. and passed the ASTM F803 standard in 1998.[16] The Edtl Handball model is called the Edtl Eyeshield and is lensless; it has been tested and did not pass the ASTM F803 standard.[17] The O'Neills model is called the Challenger lensless eyeguard and today is the most commonly used of the four. This model was tested in the 1980s as referenced above and was originally manufactured in the USA. It also did not pass the ASTM F803 standard.

Preliminary testing was done to refine the procedures and coordinate the force sensor and video recordings during each ball launch. Video data was captured in RAW format and later converted to MPEG4 format by Jeff Kastner, the videographer. Force sensor readings were captured by the computer in spreadsheet format and later culled down to all non-zero data by the investigators. All video and spreadsheet data are available from the USHA web site in read only format. After several dozen preliminary tests the investigators found that the impact data from the 115 degree and 90 degree angles were very similar and opted to conduct the formal testing using only the 90 degree angle and the 0 degree angle. This decision was arrived at by the

[14] http://www.edtlhandball.com
[15] https://www.oneills.com/challenger-handball-goggles.html
[16] Test results available by request from Unique Sports
[17] http://www.edtlhandball.com/news/lensless-eye-guards--are-they-safe.html

investigators given that the cost of the camera rental limited testing to only two days.

Model Results Summary

Each model summary references video files in the following format: ball type, mph, impact angle, shot#, where ball type code is b=Big Blue, r=Red21, w=White21. Example: r65_90_2.mpeg4 references Red21 ball fired at 65mph at 90 degree impact, shot #2. These video files are playable frame by frame in the Quicktime video player for any MAC or Windows based computer. Force measurement data is summarized in a table for each model. Only the maximum recorded force from all data files is shown with the corresponding elapsed time to that peak force. Entries of "N/A" indicate testing was not done because the model had already failed or no data was recorded by the force sensor system. An example of no recorded data would be the temple sensor not activating on a 0 degree impact. All failures are visible within the video files referenced for each model. Force measurement (in newtons, 1 newton=0.225 lbs) recordings from direct eye contact, the nose bridge and temple sensors are consistent with the video, though will vary in time and magnitude with each impact. Temple force measurements were taken for all models using the Red21 ball for further investigation of force transfer to the globe. Prediction of the risk of eye injury using a mathematical modeling program developed by Dr. George Hung of Rutgers University[18] and his colleagues Venkatesh Sathyanarayanan and Kausalendra Mahadas, will be used for this future study.

[18] http://omicsonline.org/homeomorphic-model-of-the-effect-of-impact-trauma-on-the-human-eye-jcsb.1000317.pdf

Blacknight Turbo

This model failed on both the 0 and 90 degree impacts at 50mph with the Red21 ball. The failures include direct eye contact by the lens, ejection of the lens from the frame, broken lens, broken nose-bridge and the attachment pins, and broken arm of the frame. See video files r50-0_1.mpeg4 for eye contact and fragment projectile and r50-90_1.mpeg4 for lens ejection as two failure examples.

Big Blue Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms
Eye	26.1, 49.6, 75.7	1.80, 0.40, 1.40
Nose Bridge	N/A, 57.8, 27.5	N/A, 0.80, 0.40
Temple	N/A	N/A

Red 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms
Eye	13.0, 33.9, 75.7	0.6, 2.2, 0.6
Nose Bridge	11.0, 38.6, 63.4	0.4, 0.6, 0.6
Temple	92.4, 78.2, N/A	0.4, 0.6, N/A

White 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms
Eye	15.7, 26.1, 44.4	0.6, 1.2, 1.8
Nose Bridge	N/A, 63.4, 30.3	N/A, 0.8, 0.6
Temple	N/A for all	N/A for all

Racket-Specs

This model failed the 0 degree impact at 50mph with the Red21 ball and no further testing was done on the other balls. The failure includes direct eye contact by the lens. Force measurement recordings from direct eye contact, the nose bridge and temple area are consistent with the video. See video files r50-0_02.mpeg4 and r50-0_03.mpeg4 for direct eye contact of the lens.

Red 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to peak Force in ms
Eye	31.3, 44.4, N/A	0.2, 0.4, N/A
Nose Bridge	90.6, 100.7, N/A	0.6, 0.4, N/A
Temple	101.9, 130.4, N/A	0.8, 1.6, N/A

Edtl Eye Shield

This model failed on the 0 degree impact at 50mph with all three balls. The failure is direct eye contact by each ball with corresponding force measurements. See video files w50-0_1.mpeg4 and b50-0_1. Additionally, the investigators noted from the video files that this lensless model introduces two other dangers that actually increase the risk of eye injury. First, ball impact on the upper or lower frame with more than half the ball diameter inside the lensless area causes the ball to rotate around the impacted frame in a whip-like fashion, adding angular momentum to the impact as it enters the eye socket. Secondly, because of this observed phenomenon, the impact area for direct eye contact is increased by slightly less than the radius of the ball both above and below the eye socket. The investigators referred to this as the "funnel effect", and is visible in video file trial_1.mpeg4, a 50mph shot during the preliminary testing phase.

Red 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms
Eye	86.1, 44.4, 65.3	0.6, 0.4, 0.2
Nose Bridge	55.1, 19.3, 27.5	1.0, 0.6, 0.6
Temple	99.5, 154.1, 251.2	3.0, 1.6, .4

White 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms

Eye	57.4, 78.3, N/A	0.4, 0.4, N/A
Nose Bridge	30.3, 22.0, N/A	1.2, 0.6, N/A
Temple	N/A for all	N/A for all

O'Neills Challenger Eye Guard

This model failed on the 0 degree impact at 50mph with the Red21 ball with direct eye contact and corresponding force measurements. See video files r50-0_1.mpeg4 and r50-0_3.mpeg4. The investigators also noted the presence of the funneling effect on this model in both videos.

Red 21 Ball:

Sensor	Peak Force 50, 65, 80 mph	Time to Peak Force in ms
Eye	80.9, N/A, N/A	0.2, N/A, N/A
Nose Bridge	46.8, N/A, N/A	0.6, N/A, N/A
Temple	78.2, 106.7. 101.9	1.8, 1.6, 0.2

Conclusions

The investigators' interpretation of the video and data is that none of the currently marketed eyewear models tested provide adequate eye protection for the sport of handball. Additionally, the two tested models that passed the ASTM F803-14 standard for squash are supposed to pass for handball; both did not. At a minimum, every model failed to prevent direct contact of the globe by either the ball or the eyewear. Players wearing any of the four tested models that are unaware of these facts may have a false sense of security that they have at least some protection. Additionally, because of the discovery of the funnel effect, lensless models actually increase the risk of eye injury.

Fortunately, eye injuries in handball are quite rare, however, the consequences of such an injury are catastrophic. The USHA recognized this in 1988 when it mandated eyewear usage in sanctioned events. The USHA does recommend lensed models in the rule book and sells ASTM approved ones. The investigators currently have an open dialog with the ASTM to get the F803 modified for the sport of handball based on the evidence of the test data. Additionally, the investigators have informed Unique Sports that their marketed eyewear fails the ASTM F803 standard when used for handball.

Finally, it is the investigators' desire to make the data and video of their testing widely available in order to stimulate the innovation of better protective eyewear for the safety of those who play the sport of handball.