

**ROUTING AND ACTION**

**MEMORANDUM**

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ROUTING

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TO:(1) Humans in Complex Systems Branch (HCxS) (Hung, Chou)

Report is available for review

(2) Proposal Files Report No.:

Proposal Number: 67080-HC.22

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DESCRIPTION OF MATERIAL

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CONTRACT OR GRANT NUMBER: W911NF-15-1-0390

INSTITUTION: Duke University

PRINCIPAL INVESTIGATOR: Lawrence Appelbaum

TYPE REPORT: Final Report

DATE RECEIVED: 10/1/23 1:52AM

PERIOD COVERED: 7/10/15 12:00AM through 5/16/23 12:00AM

TITLE: Final Report: Neurophysiology and Cognitive Neuroscience (8.4): Sensorimotor Function in Elite Soldiers and Athletes

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ACTION TAKEN BY DIVISION

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(x) Report has been reviewed for technical sufficiency and IS  IS NOT  satisfactory.

(x) Based on my technical review, I have identified no OPSEC or Technology Protection concerns that need to be addressed regarding this report.

(x) Performance of the research effort was accomplished in a satisfactory manner and all other technical requirements have been fulfilled.

(x) Based upon my knowledge of the research project, I agree with the patent information disclosed.

Approved by SSL\CHOU.PO.HUNG on 10/1/23 9:31AM

ARO FORM 36-E

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) 01-10-2023		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 10-Jul-2015 - 16-May-2023	
4. TITLE AND SUBTITLE Final Report: Neurophysiology and Cognitive Neuroscience (8.4): Sensorimotor Function in Elite Soldiers and Athletes			5a. CONTRACT NUMBER W911NF-15-1-0390		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 611102		
6. AUTHORS			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES Duke University C/O Office of Research Support 2200 W. Main St., Ste. 200 Durham, NC 27705 -4677			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 67080-HC.22		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Lawrence Appelbaum
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 919-943-7491

# RPPR Final Report

## as of 01-Oct-2023

Agency Code: 21XD

Proposal Number: 67080HC

**Agreement Number: W911NF-15-1-0390**

### INVESTIGATOR(S):

**Name:** Lawrence Greg Appelbaum  
**Email:** lappelbaum@health.ucsd.edu  
**Phone Number:** 9199437491  
**Principal:** Y

Organization: **Duke University**

Address: C/O Office of Research Support, Durham, NC 277054677

Country: USA

DUNS Number: 044387793

EIN: 560532129

**Report Date:** 16-Aug-2023

Date Received: 01-Oct-2023

**Final Report** for Period Beginning 10-Jul-2015 and Ending 16-May-2023

**Title:** Neurophysiology and Cognitive Neuroscience (8.4): Sensorimotor Function in Elite Soldiers and Athletes

**Begin Performance Period:** 10-Jul-2015

**End Performance Period:** 16-May-2023

**Report Term:** 0-Other

Submitted By: Lawrence Appelbaum

Email: lappelbaum@health.ucsd.edu

Phone: (919) 943-7491

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

### STEM Degrees:

### STEM Participants:

**Major Goals:** Success in many human endeavors requires individuals to efficiently process visual information in order to generate swift and appropriate motor actions. The essential nature of such "sensorimotor skills" is particularly important in activities such as athletics, military engagement, and law enforcement where visual information can be sparse and consequences can be high. In recent years, there has been a concerted effort to understand which aspects of sensorimotor function are enhanced in high-achieving individuals so these can be considered during recruitment and scouting, or targeted in training and rehabilitation programs.

Research carried out through the parent grant of this extension proposal has taken advantage of a large-scale sensorimotor testing platform initially developed by Nike Inc., called the Sensory Station. This computerized assessment device measures 9 sensorimotor skills including visual sensitivity, attention, working memory, eye-hand coordination, and response inhibition, collected under standardized testing conditions. Through secondary data analysis of over 3300 individuals, our group has delivered on an ambitious research program to map variability across individuals of differing athletic experience and expertise, and to link performance on sensorimotor measures to statistical production in professional athletes. This approach has connected research and practice, having overcome discipline-specific limitations caused by small sample sizes, disparate tasks, and challenges of mapping laboratory experiments onto real-world outcomes.

In this proposed research extension, we will build upon these successes to address new questions about the role of sensorimotor function in real-world performance, the capacity to train these abilities to enhance performance outcomes, and the impact of concussion and rehabilitation on sensorimotor function. This research will be done synergistically with the new Duke Sports Vision Center, Co-Directed by PI Appelbaum, allowing us to conduct clinically meaningful studies with athletic populations. Moreover, through our unique connections with both professional and collegiate athletic programs, we will conduct unprecedented evaluation and training studies in elite athletes. This research is described by the following three specific aims:

**Aim 1:** Sensorimotor expertise and predictors of performance. Combining sensorimotor task data, clinical metrics, and game statistics, we will test hypotheses that sensorimotor abilities differ across levels of accomplishment, distinguish athletes, and predict on-field performance.

**Aim 2:** Training, plasticity, and translation to real-world performance. We will implement laboratory-based and applied sports training programs to test the hypothesis that these programs can enhance foundational sensorimotor abilities, as well as on-field athletic performance.

**Aim 3:** Acute concussion, vision, and rehabilitation. Using sensorimotor, clinical, and eye tracking data, we will test the hypotheses that visual screens have a reliable diagnostic value for detecting mild traumatic brain injury and that sensorimotor training can enhance rehabilitation.

**Accomplishments:** (1) Submissions or publications under ARO sponsorship during the full reporting period for

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this award. List the title of each and give the total number for each of the following categories:

(a) Papers published in peer-reviewed journals

1. Appelbaum, L.G., Lu, Y., Khanna, R., & Detwiler, K.R. (2016). The effects of sports vision training on sensorimotor abilities in collegiate softball athletes. *Athletic Training and Sports Health Care*. 8(4), 154-163. [DOI: 10.3928/19425864-20160314-01]
2. Klemish, D., Ramger, B., Vittetoe, K., Reiter, J.P., Tokdar, S. & Appelbaum, L.G (2017). Visual Abilities Distinguish Pitchers from Hitters in Professional Baseball. *Journal of Sports Sciences*. DOI: 10.1080/02640414.2017.1288296.
3. Appelbaum, L.G. & Erickson, G. (2016). Sports Vision Training: a review of the state-of-the-art in digital training techniques. *International Review of Sport and Exercise Psychology*. DOI: 10.1080/1750984X.2016.1266376
4. Burris, K., Vittetoe, K., Ramger, B., Suresh, S., Tokdar, S.T., Reiter, J.P. & Appelbaum, L.G. (2018) Sensorimotor abilities predict on-field performance in professional baseball. *Nature Scientific Reports*. 8(116), 1-9.
5. Wang, W-C., DeLang, M.D., Vittetoe, K., Ramger, B. & Appelbaum, L.G. (2018) Laterality preferences in athletes: Insights from a database of 1770 male athletes. *American Journal of Sports Science*; 6(1), 20-25.
6. Rao, H.M., Khanna, R., Zielinski, D.J., Lu, Y., Clements, J.M., Potter, N.D., Sommer, M.A., Kopper, R. & Appelbaum, L.G. (2018) Sensorimotor learning during a marksmanship task in immersive virtual reality. *Frontiers in Psychology*. 9(58).
7. Liu, S., Ferris, L. M., Hilbig, S., Asamo, E., LaRue, J. L., Lyon, D., Connolly, K., Port, N., & Appelbaum, L. G. (2020). Dynamic vision training transfers positively to batting performance among collegiate baseball batters. *Psychology of Sports and Exercise*. 51(1), 101759.
8. Liu, S., Edmunds, F., Burris, K., & Appelbaum, L. G., (2020). Visual and oculomotor abilities predict professional baseball batting performance. *International Journal of Performance Analysis in Sport*. 20(4). 683-700.
9. Cox, M. L., Deng, Z-D, Palmer, H., Beynel, L., Watts, A., Young, J. R., Lisanby, S. H., Migaly, J. & Appelbaum, L. G. (2020). Utilizing transcranial direct current stimulation to enhance laparoscopic technical skills training: A randomized controlled trial. *Brain Stimulation*. 13(3). 863-872.
10. Burris, K., Liu, S., & Appelbaum, L. G. (2020). Visual-motor expertise in athletes: Insights from semiparametric modeling of 2317 athletes tested on the Nike SPARQ Sensory Station. *Journal of Sports Sciences*. 38(3).
11. Wilkins, L. & Appelbaum, L. G. (2020). An early review of stroboscopic visual training: Insights, challenges and accomplishments to guide future studies. *International Review of Sport and Exercise Psychology*. 13(1)
12. Laby, D. & Appelbaum, L.G. (2021) Vision and On-field Performance: A Critical Review of Visual Assessment and Training Studies with Athletes. *Optometry and Vision Science*. 98(7):723-731
13. Fogt, N., Appelbaum, L.G., Dalton, K., Erickson, G. & Gray, R. (2021) Guest Editorial: Visual function and sports performance. *Optometry and Vision Science*. 98(7):669-671, July 2021.
14. Liu, S., Clements, J.M., Kirsch, E.P., Rao, H., Zielinski, D. J., Lu, Y., Mainsah, B.O., Potter, N.D., Sommer, M. A., Kopper, R., and Appelbaum, L. G. (2021) Psychophysiological Markers of Performance and Learning during Simulated Marksmanship in Immersive Virtual Reality. *Journal of Cognitive Neuroscience*. 33(7); 1253-1270
15. Laby, D.M. & Appelbaum, L.G., (2021) Comment on Nascimento et al. Citations Network Analysis of Vision and Sport. *International Journal of Environmental Research and Public Health*. 2021; 18(12):6488.
16. Liu, S., Donaldson, R., Subramaniam, A., Palmer, H., Champion, C., Cox, M., & Appelbaum, L.G. (2021) Developing Expert Gaze Pattern in Laparoscopic Surgery Requires More than Behavioral Training. *Journal of Eye Movement Research*. 14(2)
17. Liu, S., Folstein, J.R., Appelbaum, L.G., and Tenenbaum, G. (2021) The mechanism of controlling unwanted intrusive thoughts: A randomized controlled study with choking experiences in athletes. *Journal of Experimental Psychology: Human Perception and Performance*. 47(10): 1395-1408
18. Young, J.R., Galla, J.T., & Appelbaum, L.G., (2021) Transcranial Magnetic Stimulation Treatment for Smoking Cessation: An Introduction for Primary Care Clinicians. *American Journal of Medicine*. 134(11): 1339-1343
19. Laby, D., Appelbaum, L.G., Hülndünker, T., and Putrino, D., (2022) Editorial: Neural Mechanisms of Perceptual-Cognitive Expertise in Elite Performers. *Frontiers in Human Neuroscience*.
20. Subramaniam, A., Liu, S., Lochhead, L., & Appelbaum, L.G., (2022) A systematic review of transcranial direct current stimulation on eye movements and associated psychological function. *Reviews in the Neurosciences*. 31;34(3):349-364.
21. Donaldson, R., Liu, S., & Appelbaum, L.G., (2022) Can Electricity Help Surgeons' Brains Learn Faster? *Frontiers in Young Minds*. 10(767519). doi: 10.3389/frym.2022.767519
22. Stolz, L.A., Liu, S., Asamo, E., & Appelbaum, L.G., (2023) Neurobehavioral measures of coincidence anticipation timing. *Journal of Vision*. 23(16)
23. Dambrosia, C., Aronoff-Spencer, E., Huang, E.Y., Goldhaber, N.H., Jacobsen, G., Sandler, B., Horgan, S., Appelbaum, L.G., Christensen, H., & Broderick, R.C., (2023) The physiology of intraoperative error: using electrokardiograms to understand operator performance during robot-assisted surgery simulations. *Surgical Endoscopy*. 37(6)

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24. Dambrosia, C., Aronoff-Spencer, E., Huang, E.Y., Goldhaber, N.H., Christensen, H., Broderick, R.C., & Appelbaum, L.G., (2023) The Neurophysiology of Intraoperative Error: An EEG Study of Trainee Surgeons during Robotic-Assisted Surgery Simulations. *Frontiers in Neuroergonomics*. 3(1)
25. Ho J, Liu S, Feng Z, Appelbaum LG (2023) Psychomotor and visual skills underlying position specialization in 1352 elite youth baseball players. *PLoS ONE* 18(1): e0278689.
26. Feng, Z., Lochhead, L., Kohn, J.N., and Appelbaum, L.G. (in press) Predictors of batting and pitching performance in the USA Baseball Prospect Development Pipeline. *Sports Biomechanics*

### (b) Papers published in non-peer-reviewed journals

1. Liu, S., Ferris, L. M., Hilbig, S., Asamo, E., LaRue, J. L., Lyon, D., ... & Appelbaum, L. G. (2020). Dynamic vision training transfers positively to batting performance among collegiate baseball batters. *BioRxiv preprint*.
2. Liu, S., Edmunds, F., Burris, K., & Appelbaum, L. G. (2020). Visual and oculomotor abilities predict professional batting performance. *BioRxiv preprint*.
3. Liu, S., Donaldson, R., Subramaniam, A., Palmer, H., Champion, C., Cox, M., & Appelbaum, L.G. (2020) Skill acquisition and gaze behavior during laparoscopic surgical simulation. *BioRxiv preprint*.
4. Lochhead, L. & Appelbaum, L.G., (2022) Sports Vision Research: Seeing Improvements. In *Optometric Management*

### (c) Presentations

#### i. Presentations at meetings, but not published in Conference Proceedings

1. Brain Awareness Week public lecture, March-29-2016, Presented by Dr. Greg Appelbaum
2. Duke Neuroscience Program in Research, July-29 2016, Poster presented by Ms. Kelly Vittetoe at the Duke NPR Undergraduate Research Symposium
3. "Sports Vision" Presented by Dr. Greg Appelbaum, Bassett Society Annual Meeting at Duke University, Durham NC. October 8, 2016
4. "Sports Vision Training: A Review" Presented by Dr. Greg Appelbaum, Sports Vision Consortium at Vision Service Providers, National HQ, Sacramento CA., April-11-2017
5. "What is the root of perceptual expertise in athletes and can it be trained" Presented by Dr. Greg Appelbaum, International Sports Vision Association, Annual Meeting, Park City, UT. Feb 9, 2018
6. "Applied Neuroscience to Accelerate Learning" Presented by Dr. Greg Appelbaum, Duke University, Center for Cognitive Neuroscience Seminar Series. Sept 15, 2017.

**Training Opportunities:** (2) Student/Supported Personnel Metrics for this Reporting Period (name, % supported, %Full Time Equivalent (FTE) support provided by this agreement, and total for each category):

This ARO award supported the training of numerous mentees at both Duke University and the University of California, San Diego who contributed to the scientific progress while also gaining didactic experiences.

#### (a) Graduate Students?

David Klemish, Matthew DeLang, Sunith Suresh, Kyle Burris

#### (b) Post Doctorates?

Sicong Liu

#### (c) Faculty?

Dr. Greg Appelbaum

#### (d) Undergraduate Students

Ben Ramger, Kelly Vittetoe, Rajan Khanna, Maria Naclario, Ted Feng, Jordan Baker, Jessica Ho, Ashwin Subramaniam, Leo Feng, Edem Asamo, Erickson Nichols

#### (e) Graduating Undergraduate Metrics (funded by this agreement and graduating during this reporting period):

##### i. Number who graduated during this period.

All undergraduate students have graduated except for Ted Feng, who is currently a senior at UCSD

#### (f) Masters Degrees Awarded (Name of each, Total #)?

None

#### (g) Ph.D.s Awarded (Name of each, Total #)?

Under the supervision of Dr. Appelbaum, both Matthew DeLang, Doctor of Physical Therapy, and Kyle Burris, 1, PhD in Statistics graduated

#### (h) Other Research staff (Name of each, FTE % Supported for each, Total % Supported)

None

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**Results Dissemination:** As listed above, this ARO award supported 26 articles (with 2 more currently under review) and 28 conference presentations. These scientific works have addressed primarily the development and testing of neuroscience-based approaches for optimizing human performance.

**Honors and Awards:** • 2016 Duke Neuroscience Program in Research - Awarded to Ms. Kelly Vittetoe. This fellowship, awarded through the college of arts and sciences, provided \$2000 for Ms Vittetoe to contribute her summer to research on ARO project.

- 2018 MIT Sloan Sports Analytics Research paper competition finalist.

### Protocol Activity Status:

**Technology Transfer:** As a direct result of the research supported by this ARO award, we opened the Duke Sports Vision Center (<https://dukeeyecenter.duke.edu/divisions/duke-vision-rehabilitation/duke-sports-vision-center>). This center is a joint-venture between the Urbaniak Sports Sciences Institute, the Duke Eye Center, and the Department of Psychiatry and Behavioral Sciences to provide state-of-the-art eye care and neurocognitive interventions to optimize and rehabilitate high performance vision. The center is staffed by a multidisciplinary team including specialists in ophthalmic care, sports vision, cognitive neuroscience, occupational and physical therapy and concussion rehabilitation. This academic-medicine program includes elements of both clinical care and research, measuring vision and performance outcomes to advance the field of sports vision. The clinical and training services provided in this center are the direct result of the successful research and collaborative ties that resulted from this ARO award. Moreover, the interventions used in the center have been tested and/or reviewed under support of this ARO award.

### PARTICIPANTS:

**Participant Type:** PD/PI

**Participant:** Lawrence Gregory Appelbaum

**Person Months Worked:** 3.00

Project Contribution:

National Academy Member: N

**Funding Support:**

### ARTICLES:

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Athletic Training & Sports Health Care

Publication Identifier Type: DOI

Publication Identifier: 10.3928/19425864-20160314-01

Volume: 8

Issue: 4

First Page #: 154

Date Submitted: 8/31/16 12:00AM

Date Published: 7/1/16 8:00AM

Publication Location:

**Article Title:** The Effects of Sports Vision Training on Sensorimotor Abilities in Collegiate Softball Athletes

**Authors:** L. Gregory Appelbaum, Yvonne Lu, Rajan Khanna, Kimberly R. Detwiler

**Keywords:** SVT, sensorimotor, sports training

**Abstract:** Sports vision training (SVT) relies on the notion that practice with demanding perceptual or oculomotor tasks can improve the ability to process and respond to what is seen. In this exploratory investigation, the authors tested the influence of SVT on sensorimotor abilities through data collected during an applied intervention performed by the University of Texas varsity softball team. This intervention entailed multiple weeks of SVT drills completed in conjunction with typical softball activities. Baseline and post-training performance on nine tasks comprising the Nike Sensory Station battery were compared between 15 athletes who underwent SVT and 10 teammates who did not. Results indicate significant relative improvements for the SVT group in three tasks (Near-Far Quickness, Target Capture, and Go/No-Go), although these did not relate to the number of drills practiced. These findings suggest that the SVT program under consideration may have led to improvements in sensorimotor skills

**Distribution Statement:** 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** International Review of Sport and Exercise Psychology

Publication Identifier Type: DOI

Publication Identifier: 10.1080/1750984X.2016.1266376

Volume: 11

Issue: 1

First Page #: 1

Date Submitted: 8/16/20 12:00AM

Date Published: 8/1/18 7:12AM

Publication Location:

**Article Title:** Sports Vision Training; a review of the state-of-the-art in digital training techniques

**Authors:** Appelbaum, L.G. & Erickson, G

**Keywords:** Sports Vision Training, Enhancement, Perception, Learning, Simulations

**Abstract:** Athletes need excellent vision to perform well in their sports, and many athletes have turned to vision training programs as a way to augment their traditional training regimen. The growing practice of 'sports vision training' relies on the notion that practice with demanding visual perceptual, cognitive, or oculomotor tasks can improve the ability to process and respond to what is seen, thereby improving sport performance. This enterprise is not necessarily new, but has been advanced greatly in the past few years by new digital technology that can be deployed during natural training activities, by perceptual-learning-inspired training programs, and by virtual reality simulations that can recreate and augment sporting contexts to promote certain sports-specific visual and cognitive abilities. These improved abilities may, in turn, instill a competitive advantage on the playing field, underscoring the potential value of these approaches. This article reviews emerging approaches, technol

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Acknowledged Federal Support: Y

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published  
**Journal:** Journal of Sports Science  
Publication Identifier Type: Other      Publication Identifier: 10.1080/02640414.2017.1288296.  
Volume: 36      Issue: 2      First Page #: 171  
Date Submitted: 8/16/20 12:00AM      Date Published: 9/1/18 7:18AM  
Publication Location:

**Article Title:** Visual Abilities Distinguish Pitchers from Hitters in Professional Baseball

**Authors:** Klemish, D., Ramger, B., Vittetoe, K., Reiter, J.P., Tokdar, S. & Appelbaum, L.G

**Keywords:** Cognition, Expert Performance, Perception, Baseball, Vision

**Abstract:** This study aims to evaluate the possibility that differences in sensorimotor abilities exist between hitters and pitchers in a large cohort of baseball players of varying levels of experience. Secondary data analysis was performed on 9 sensorimotor tasks comprising the Nike Sensory Station assessment battery. Bayesian hierarchical regression modeling was applied to test for differences between pitchers and hitters in data from 566 baseball players (112 high school, 85 college, and 369 professional) collected at 20 different testing centers between April 2010 and December 2014. Explanatory variables including height, handedness, eye dominance, concussion history, and player position were modeled along with age curves using basis regression splines. Regression analyses revealed better performance for hitters relative to pitchers at the professional level in the visual clarity and depth perception tasks, but these differences did not exist at the high school or college levels. No significant

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**Acknowledged Federal Support:** Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published  
**Journal:** International Review of Sport and Exercise Psychology  
Publication Identifier Type: DOI      Publication Identifier: 10.1080/1750984X.2019.1582081  
Volume:      Issue:      First Page #: 1  
Date Submitted: 8/28/19 12:00AM      Date Published: 3/1/19 10:00AM  
Publication Location:

**Article Title:** An early review of stroboscopic visual training: insights, challenges and accomplishments to guide future studies

**Authors:** Luke Wilkins, Lawrence Gregory Appelbaum

**Keywords:** Sports Vision; Stroboscopic Training; Review

**Abstract:** Stroboscopic visual training (SVT) is a form of training in which an individual practices a task under intermittent visual conditions with the intention of enhancing subsequent performance under normal visual conditions. Training with stroboscopic devices is theorized to improve important visual, perceptual, and cognitive skills, which in turn transfers to enhanced sporting performance. Indeed, while there is an abundance of anecdotal evidence suggesting benefits of strobe training, empirical evidence is rarer and less conclusive. This lack of clarity is due, in part, to the challenging methodological issues faced when conducting experimental vision training studies in applied contexts. The present paper is an early review of the research to date with a focus on the key methodological decisions, such as the training and testing protocols employed, participant samples and control groups used, and practical considerations that enable such training in applied settings. Whilst still at an

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**Acknowledged Federal Support:** Y

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** American Journal of Sports Science

Publication Identifier Type: DOI

Publication Identifier: 10.11648/j.ajss.20180601.14

Volume: 6

Issue: 1

First Page #: 20

Date Submitted: 8/28/19 12:00AM

Date Published:

Publication Location:

**Article Title:** Laterality Preferences in Athletes: Insights from a Database of 1770 Male Athletes

**Authors:** Wei-Chun Wang

**Keywords:** Laterality Preferences, Handedness, Footedness, Eye Dominance, Athletes

**Abstract:** Laterality preferences are inherent in most sensory and motor activities, and sports are certainly one domain wherein these preferences might impact performance and outcomes. The fact that most individuals exhibit laterality preferences and that sporting demands differentially draw on these abilities makes the expression of these preferences in athletes a topic ripe for exploration. To fill this gap, the current report describes hand, foot, and eye laterality preferences in a large cohort of 1770 male athletes tested on the Nike Sensory Station assessment battery. Self-reported hand and foot preferences, as well as eye dominance measured through the Miles Test, were compared across athletes of different experience levels (middle/high school, college, professional athletes) and primary sports (baseball, basketball, football, hockey, soccer) to evaluate group differences in laterality preferences. Results revealed group differences, most notably a higher proportion of left-hand and left-

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**Acknowledged Federal Support:** Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Scientific Reports

Publication Identifier Type: DOI

Publication Identifier: 10.1038/s41598-017-18565-7

Volume: 8

Issue: 1

First Page #:

Date Submitted: 8/28/19 12:00AM

Date Published: 1/1/18 5:00AM

Publication Location:

**Article Title:** Sensorimotor abilities predict on-field performance in professional baseball

**Authors:** Kyle Burris, Kelly Vittetoe, Benjamin Ramger, Sunith Suresh, Surya T. Tokdar, Jerome P. Reiter, L. Gre

**Keywords:** Sports Vision; Baseball, Bayesian Modeling

**Abstract:** Baseball players must be able to see and react in an instant, yet it is hotly debated whether superior performance is associated with superior sensorimotor abilities. In this study, we compare sensorimotor abilities, measured through 8 psychomotor tasks comprising the Nike Sensory Station assessment battery, and game statistics in a sample of 252 professional baseball players to evaluate the links between sensorimotor skills and on-field performance. For this purpose, we develop a series of Bayesian hierarchical latent variable models enabling us to compare statistics across professional baseball leagues. Within this framework, we find that sensorimotor abilities are significant predictors of on-base percentage, walk rate and strikeout rate, accounting for age, position, and league. We find no such relationship for either slugging percentage or fielder-independent pitching. The pattern of results suggests performance contributions from both visual-sensory and visual-motor abilities and

**Distribution Statement:** 3-Distribution authorized to U.S. Government Agencies and their contractors  
**Acknowledged Federal Support:** Y

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Journal of Sports Sciences

Publication Identifier Type: DOI

Publication Identifier: 10.1080/02640414.2019.1698090

Volume: 38

Issue: 3

First Page #: 320

Date Submitted: 8/16/20 12:00AM

Date Published: 11/1/19 4:00AM

Publication Location:

**Article Title:** Visual-motor expertise in athletes; Insights from semiparametric modelling of 2317 athletes tested on the Nike SPARQ Sensory Station

**Authors:** Kyle Burris, Sicong Liu, Lawrence Appelbaum

**Keywords:** Vision; motor control; expertise; copula

**Abstract:** Elite athletes not only run faster, hit harder, and jump higher, but also see and react better. However, the specific visual-motor skills that differentiate high-achieving athletes are still not well understood. In this paper we examine 2317 athletes (1871 male) tested on the Nike SPARQ Sensory Station, a digital test battery measuring visual, perceptual and motor skills relevant for sports performance. We develop a multivariate Gaussian transformation model to robustly estimate visual-motor differences by level, gender, and sport type. Results demonstrate that visual-motor performance is superior for athletes at higher levels, with males faster at near-far eye movements and females faster at eye-hand reaction times. Interestingly, athletes who play interceptive sports such as baseball and tennis exhibit better measures of visual clarity, contrast sensitivity and simple reaction time, while athletes from strategic sports like soccer and basketball have higher measures of spatial worki

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Acknowledged Federal Support: Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Brain Stimulation

Publication Identifier Type: DOI

Publication Identifier: 10.1016/j.brs.2020.03.009

Volume: 13

Issue: 3

First Page #: 863

Date Submitted: 8/16/20 12:00AM

Date Published: 5/1/20 4:00AM

Publication Location:

**Article Title:** Utilizing transcranial direct current stimulation to enhance laparoscopic technical skills training; A randomized controlled trial

**Authors:** Morgan L. Cox, Zhi-De Deng, Hannah Palmer, Amanda Watts, Lysianne Beynel, Jonathan R. Young, S:

**Keywords:** Transcranial direct current stimulation; FLS Peg transfer task; Bilateral motor cortex; Supplementary motor area; Visual-motor learning

**Abstract:** Elite athletes not only run faster, hit harder, and jump higher, but also see and react better. However, the specific visual-motor skills that differentiate high-achieving athletes are still not well understood. In this paper we examine 2317 athletes (1871 male) tested on the Nike SPARQ Sensory Station, a digital test battery measuring visual, perceptual and motor skills relevant for sports performance. We develop a multivariate Gaussian transformation model to robustly estimate visual-motor differences by level, gender, and sport type. Results demonstrate that visual-motor performance is superior for athletes at higher levels, with males faster at near-far eye movements and females faster at eye-hand reaction times. Interestingly, athletes who play interceptive sports such as baseball and tennis exhibit better measures of visual clarity, contrast sensitivity and simple reaction time, while athletes from strategic sports like soccer and basketball have higher measures of spatial worki

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## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** International Journal of Performance Analysis in Sport

Publication Identifier Type: DOI

Publication Identifier: 10.1080/24748668.2020.1777819

Volume: 20

Issue: 4

First Page #: 683

Date Submitted: 8/16/20 12:00AM

Date Published: 6/1/20 4:00AM

Publication Location:

**Article Title:** Visual and oculomotor abilities predict professional baseball batting performance

**Authors:** Sicong Liu, Frederick R. Edmunds, Kyle Burris, Lawrence Gregory Appelbaum

**Keywords:** Expertise; baseball; vision; visual-motor abilities; eye tracking; plate discipline performance

**Abstract:** Elite athletes not only run faster, hit harder, and jump higher, but also see and react better. However, the specific visual-motor skills that differentiate high-achieving athletes are still not well understood. In this paper we examine 2317 athletes (1871 male) tested on the Nike SPARQ Sensory Station, a digital test battery measuring visual, perceptual and motor skills relevant for sports performance. We develop a multivariate Gaussian transformation model to robustly estimate visual-motor differences by level, gender, and sport type. Results demonstrate that visual-motor performance is superior for athletes at higher levels, with males faster at near-far eye movements and females faster at eye-hand reaction times. Interestingly, athletes who play interceptive sports such as baseball and tennis exhibit better measures of visual clarity, contrast sensitivity and simple reaction time, while athletes from strategic sports like soccer and basketball have higher measures of spatial worki

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**Acknowledged Federal Support:** Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Psychology of Sport and Exercise

Publication Identifier Type: DOI

Publication Identifier: 10.1016/j.psychsport.2020.101759

Volume: 51

Issue:

First Page #: 101759

Date Submitted: 8/16/20 12:00AM

Date Published: 11/1/20 4:00AM

Publication Location:

**Article Title:** Dynamic vision training transfers positively to batting practice performance among collegiate baseball batters

**Authors:** Sicong Liu, Lyndsey M. Ferris, Susan Hilbig, Edem Asamoah, John L. LaRue, Don Lyon, Katie Connolly,

**Keywords:** vision; baseball; learning

**Abstract:** Elite athletes not only run faster, hit harder, and jump higher, but also see and react better. However, the specific visual-motor skills that differentiate high-achieving athletes are still not well understood. In this paper we examine 2317 athletes (1871 male) tested on the Nike SPARQ Sensory Station, a digital test battery measuring visual, perceptual and motor skills relevant for sports performance. We develop a multivariate Gaussian transformation model to robustly estimate visual-motor differences by level, gender, and sport type. Results demonstrate that visual-motor performance is superior for athletes at higher levels, with males faster at near-far eye movements and females faster at eye-hand reaction times. Interestingly, athletes who play interceptive sports such as baseball and tennis exhibit better measures of visual clarity, contrast sensitivity and simple reaction time, while athletes from strategic sports like soccer and basketball have higher measures of spatial worki

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**Acknowledged Federal Support:** Y

**RPPR Final Report**  
as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Optometry and Vision Science

Publication Identifier Type: DOI

Publication Identifier: 10.1097/OPX.0000000000001729

Volume: 98

Issue: 7

First Page #: 723

Date Submitted: 8/27/21 12:00AM

Date Published: 7/1/21 7:00AM

Publication Location:

**Article Title:** Review: Vision and On-field Performance: A Critical Review of Visual Assessment and Training Studies with Athletes

**Authors:** Daniel M. Laby, Lawrence Gregory Appelbaum

**Keywords:** vision; athletes; review

**Abstract:** Sports vision is an emerging field that seeks to establish the relationships between visual function and sports performance. Here we provide the first critical review of empirical studies that attempt to link visual assessments and vision training to competitive game performance. Vision is essential to producing controlled movement, and therefore, it is intuitive that better visual abilities should relate to better sporting performance. This notion has been central to the field of sports vision, an area of study that seeks to determine the visual skills that underlie optimal sports performance and investigate approaches to train these abilities to improve sports performance. Although this field now contains hundreds of published articles addressing visual assessment and training in athletes, relatively few have attempted to directly link these capabilities to on-field production statistics from competitive matches. The objectives of this article are both to describe the theoretical

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support: Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Optometry and Vision Science

Publication Identifier Type: DOI

Publication Identifier: 10.1097/OPX.0000000000001717

Volume: 98

Issue: 7

First Page #: 669

Date Submitted: 8/27/21 12:00AM

Date Published: 7/1/21 7:00AM

Publication Location:

**Article Title:** Guest Editorial: Visual Function and Sports Performance

**Authors:** Nick Fogt, Lawrence Gregory Appelbaum, Kristine Dalton, Graham Erickson, Rob Gray

**Keywords:** vision; sports

**Abstract:** Sports vision is an emerging field that seeks to establish the relationships between visual function and sports performance. Here we provide the first critical review of empirical studies that attempt to link visual assessments and vision training to competitive game performance. Vision is essential to producing controlled movement, and therefore, it is intuitive that better visual abilities should relate to better sporting performance. This notion has been central to the field of sports vision, an area of study that seeks to determine the visual skills that underlie optimal sports performance and investigate approaches to train these abilities to improve sports performance. Although this field now contains hundreds of published articles addressing visual assessment and training in athletes, relatively few have attempted to directly link these capabilities to on-field production statistics from competitive matches. The objectives of this article are both to describe the theoretical

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Acknowledged Federal Support: Y

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Journal of Cognitive Neuroscience

Publication Identifier Type: DOI

Publication Identifier: 10.1162/jocn\_a\_01713

Volume: 33

Issue: 7

First Page #: 1253

Date Submitted: 8/27/21 12:00AM

Date Published: 7/1/21 7:00AM

Publication Location:

**Article Title:** Psychophysiological Markers of Performance and Learning during Simulated Marksmanship in Immersive Virtual Reality

**Authors:** Sicong Liu, Jillian M. Clements, Elayna P. Kirsch, Hrishikesh M. Rao, David J. Zielinski, Yvonne Lu, Boy

**Keywords:** performance; simulation' virtual reality; EEG

**Abstract:** Sports vision is an emerging field that seeks to establish the relationships between visual function and sports performance. Here we provide the first critical review of empirical studies that attempt to link visual assessments and vision training to competitive game performance. Vision is essential to producing controlled movement, and therefore, it is intuitive that better visual abilities should relate to better sporting performance. This notion has been central to the field of sports vision, an area of study that seeks to determine the visual skills that underlie optimal sports performance and investigate approaches to train these abilities to improve sports performance. Although this field now contains hundreds of published articles addressing visual assessment and training in athletes, relatively few have attempted to directly link these capabilities to on-field production statistics from competitive matches. The objectives of this article are both to describe the theoretical

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Acknowledged Federal Support: Y

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** International Journal of Environmental Research and Public Health

Publication Identifier Type: DOI

Publication Identifier: 10.3390/ijerph18126488

Volume: 18

Issue: 12

First Page #: 6488

Date Submitted: 8/27/21 12:00AM

Date Published: 6/1/21 7:00AM

Publication Location:

**Article Title:** Comment on Nascimento et al. Citations Network Analysis of Vision and Sport. Int. J. Environ. Res. Public Health 2020, 17, 7574

**Authors:** Daniel M. Laby, Lawrence G. Appelbaum

**Keywords:** network citation; sports; vision

**Abstract:** Sports vision is an emerging field that seeks to establish the relationships between visual function and sports performance. Here we provide the first critical review of empirical studies that attempt to link visual assessments and vision training to competitive game performance. Vision is essential to producing controlled movement, and therefore, it is intuitive that better visual abilities should relate to better sporting performance. This notion has been central to the field of sports vision, an area of study that seeks to determine the visual skills that underlie optimal sports performance and investigate approaches to train these abilities to improve sports performance. Although this field now contains hundreds of published articles addressing visual assessment and training in athletes, relatively few have attempted to directly link these capabilities to on-field production statistics from competitive matches. The objectives of this article are both to describe the theoretical

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Acknowledged Federal Support: Y

## RPPR Final Report as of 01-Oct-2023

**Publication Type:** Journal Article      Peer Reviewed: Y      **Publication Status:** 1-Published

**Journal:** Journal of Eye Movement Research

Publication Identifier Type: DOI

Publication Identifier: 10.16910/jemr.14.2.2

Volume: 14

Issue: 2

First Page #:

Date Submitted: 8/27/21 12:00AM

Date Published: 3/1/21 8:00AM

Publication Location:

**Article Title:** Developing expert gaze pattern in laparoscopic surgery requires more than behavioral training

**Authors:** Sicong Liu, Rachel Donaldson, Ashwin Subramaniam, Hannah Palmer, Cosette D. Champion, Morgan L

**Keywords:** Fundamentals of laparoscopic surgery, eye tracking, gaze, area of interest, attention, learning, expertise

**Abstract:** Sports vision is an emerging field that seeks to establish the relationships between visual function and sports performance. Here we provide the first critical review of empirical studies that attempt to link visual assessments and vision training to competitive game performance. Vision is essential to producing controlled movement, and therefore, it is intuitive that better visual abilities should relate to better sporting performance. This notion has been central to the field of sports vision, an area of study that seeks to determine the visual skills that underlie optimal sports performance and investigate approaches to train these abilities to improve sports performance. Although this field now contains hundreds of published articles addressing visual assessment and training in athletes, relatively few have attempted to directly link these capabilities to on-field production statistics from competitive matches. The objectives of this article are both to describe the theoretical

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Acknowledged Federal Support: Y

**Publication Type:** Journal Article      Peer Reviewed:      **Publication Status:** 1-Published

**Journal:** Brain Stimulation

Publication Identifier Type: DOI

Publication Identifier: 10.1016/j.brs.2020.03.009

Volume: 13

Issue: 3

First Page #:

Date Submitted:

Date Published: 5/1/20 12:00AM

Publication Location:

**Article Title:** Utilizing transcranial direct current stimulation to enhance laparoscopic technical skills training: A randomized controlled trial

**Authors:** Morgan L. Cox, Zhi-De Deng, Hannah Palmer, Amanda Watts, Lysianne Beynel, Jonathan R. Young, S:

**Keywords:** Neurology (clinical)

**Abstract:**

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support:

**Publication Type:** Journal Article      Peer Reviewed:      **Publication Status:** 1-Published

**Journal:** Surgical Endoscopy

Publication Identifier Type: DOI

Publication Identifier: 10.1007/s00464-023-09957-0

Volume: 37

Issue: 6

First Page #:

Date Submitted:

Date Published: 3/2/23 12:00AM

Publication Location:

**Article Title:** The physiology of intraoperative error: using electrokardiograms to understand operator performance during robot-assisted surgery simulations

**Authors:** Christopher D'Ambrosia, Eliah Aronoff-Spencer, Estella Y. Huang, Nicole H. Goldhaber, Garth R. Jacob

**Keywords:** Surgery

**Abstract:**

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support:

**RPPR Final Report**  
as of 01-Oct-2023

**Publication Type:** Journal Article

Peer Reviewed:

**Publication Status:** 1-Published

**Journal:** PLOS ONE

Publication Identifier Type: DOI

Publication Identifier: 10.1371/journal.pone.0278689

Volume: 18

Issue: 1

First Page #:

Date Submitted:

Date Published: 1/19/23 12:00AM

Publication Location:

**Article Title:** Psychomotor and visual skills underlying position specialization in 1352 elite youth baseball players

**Authors:** Jessica Ho, Sicong Liu, Zeyu Feng, Lawrence Gregory Appelbaum,

**Keywords:** Multidisciplinary

**Abstract:**

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

Acknowledged Federal Support:

**CONFERENCE PAPERS:**

**Publication Type:** Conference Paper or Presentation

**Publication Status:** 1-Published

**Conference Name:** 2018 IEEE Conference on Virtual Reality and 3D User Interfaces &#x26;x28&#x3b;  
VR&#x26;x29&#x3b;

Date Received: 16-Aug-2020

Conference Date: 18-Mar-2018

Date Published: 19-Dec-2018

Conference Location: Tuebingen&#x26;x2f&#x3b;Reutlingen, Germany

**Paper Title:** Neurophysiology of Visual-Motor Learning During a Simulated Marksmanship Task in Immersive Virtual Reality

**Authors:** 2.&#x26;x9&#x3b;Clements, J. M., Kopper, R., Zielinski, D. J., Rao, H., Sommer, M. A., Kirsch, E

Acknowledged Federal Support: Y

**Partners**

I certify that the information in the report is complete and accurate:

Signature: Lawrence G. Appelbaum

Signature Date: 10/1/23 1:52AM

**“The Report Documentation Page (SF298) Continuation Sheet (Enclosure 2)” or a plain piece of paper must include brief, but complete, information for each of the following categories:**

**(1) Submissions or publications under ARO sponsorship during the full reporting period for this award. List the title of each and give the total number for each of the following categories:**

**(a) Papers published in peer-reviewed journals**

1. Appelbaum, L.G., Lu, Y., Khanna, R., & Detwiler, K.R. (2016). The effects of sports vision training on sensorimotor abilities in collegiate softball athletes. *Athletic Training and Sports Health Care*. 8(4), 154-163. [DOI: 10.3928/19425864-20160314-01]
2. Klemish, D., Ramger, B., Vittetoe, K., Reiter, J.P., Tokdar, S. & Appelbaum, L.G (2017). Visual Abilities Distinguish Pitchers from Hitters in Professional Baseball. *Journal of Sports Sciences*. DOI: 10.1080/02640414.2017.1288296.
3. Appelbaum, L.G. & Erickson, G. (2016). Sports Vision Training: a review of the state-of-the-art in digital training techniques. *International Review of Sport and Exercise Psychology*. DOI: 10.1080/1750984X.2016.1266376
4. Burris, K., Vittetoe, K., Ramger, B., Suresh, S., Tokdar, S.T., Reiter, J.P. & Appelbaum, L.G. (2018) Sensorimotor abilities predict on-field performance in professional baseball. *Nature Scientific Reports*. 8(116), 1-9.
5. Wang, W-C., DeLang, M.D., Vittetoe, K., Ramger, B. & Appelbaum, L.G. (2018) Laterality preferences in athletes: Insights from a database of 1770 male athletes. *American Journal of Sports Science*; 6(1), 20-25.
6. Rao, H.M., Khanna, R., Zielinski, D.J., Lu, Y., Clements, J.M., Potter, N.D., Sommer, M.A., Kopper, R. & Appelbaum, L.G. (2018) Sensorimotor learning during a marksmanship task in immersive virtual reality. *Frontiers in Psychology*. 9(58).
7. Liu, S., Ferris, L. M., Hilbig, S., Asamo, E., LaRue, J. L., Lyon, D., Connolly, K., Port, N., & Appelbaum, L. G. (2020). Dynamic vision training transfers positively to batting performance among collegiate baseball batters. *Psychology of Sports and Exercise*. 51(1), 101759.
8. Liu, S., Edmunds, F., Burris, K., & Appelbaum, L. G., (2020). Visual and oculomotor abilities predict professional baseball batting performance. *International Journal of Performance Analysis in Sport*. 20(4). 683-700.
9. Cox, M. L., Deng, Z-D, Palmer, H., Beynel, L., Watts, A., Young, J. R., Lisanby, S. H., Migaly, J. & Appelbaum, L. G. (2020). Utilizing transcranial direct current stimulation to enhance laparoscopic technical skills training: A randomized controlled trial. *Brain Stimulation*. 13(3). 863-872.

10. Burris, K., Liu, S., & Appelbaum, L. G. (2020). Visual-motor expertise in athletes: Insights from semiparametric modeling of 2317 athletes tested on the Nike SPARQ Sensory Station. *Journal of Sports Sciences*. 38(3).
11. Wilkins, L. & Appelbaum, L. G. (2020). An early review of stroboscopic visual training: Insights, challenges and accomplishments to guide future studies. *International Review of Sport and Exercise Psychology*. 13(1)
12. Laby, D. & Appelbaum, L.G. (2021) Vision and On-field Performance: A Critical Review of Visual Assessment and Training Studies with Athletes. *Optometry and Vision Science*. 98(7):723-731
13. Fogt, N., Appelbaum, L.G., Dalton, K., Erickson, G. & Gray, R. (2021) Guest Editorial: Visual function and sports performance. *Optometry and Vision Science*. 98(7):669-671, July 2021.
14. Liu, S., Clements, J.M., Kirsch, E.P., Rao, H., Zielinski, D. J., Lu, Y., Mainsah, B.O., Potter, N.D., Sommer, M. A., Kopper, R., and Appelbaum, L. G. (2021) Psychophysiological Markers of Performance and Learning during Simulated Marksmanship in Immersive Virtual Reality. *Journal of Cognitive Neuroscience*. 33(7); 1253-1270
15. Laby, D.M. & Appelbaum, L.G., (2021) Comment on Nascimento et al. Citations Network Analysis of Vision and Sport. *International Journal of Environmental Research and Public Health*. 2021; 18(12):6488.
16. Liu, S., Donaldson, R., Subramaniam, A., Palmer, H., Champion, C., Cox, M., & Appelbaum, L.G. (2021) Developing Expert Gaze Pattern in Laparoscopic Surgery Requires More than Behavioral Training. *Journal of Eye Movement Research*. 14(2)
17. Liu, S., Folstein, J.R., Appelbaum, L.G., and Tenenbaum, G. (2021) The mechanism of controlling unwanted intrusive thoughts: A randomized controlled study with choking experiences in athletes. *Journal of Experimental Psychology: Human Perception and Performance*. 47(10): 1395-1408
18. Young, J.R., Galla, J.T., & Appelbaum, L.G., (2021) Transcranial Magnetic Stimulation Treatment for Smoking Cessation: An Introduction for Primary Care Clinicians. *American Journal of Medicine*. 134(11): 1339-1343
19. Laby, D., Appelbaum, L.G., Hülzdünker, T., and Putrino, D., (2022) Editorial: Neural Mechanisms of Perceptual-Cognitive Expertise in Elite Performers. *Frontiers in Human Neuroscience*.
20. Subramaniam, A., Liu, S., Lochhead, L., & Appelbaum, L.G., (2022) A systematic review of transcranial direct current stimulation on eye movements and associated psychological function. *Reviews in the Neurosciences*. 31;34(3):349-364.
21. Donaldson, R., Liu, S., & Appelbaum, L.G., (2022) Can Electricity Help Surgeons' Brains Learn Faster? *Frontiers in Young Minds*. 10(767519). doi: 10.3389/frym.2022.767519

22. Stolz, L.A., Liu, S., Asamo, E., & Appelbaum, L.G., (2023) Neurobehavioral measures of coincidence anticipation timing. *Journal of Vision*. 23(16)
23. Dambrosia, C., Aronoff-Spencer, E., Huang, E.Y., Goldhaber, N.H., Jacobsen, G., Sandler, B., Horgan, S., Appelbaum, L.G., Christensen, H., & Broderick, R.C., (2023) The physiology of intraoperative error: using electrokardiograms to understand operator performance during robot-assisted surgery simulations. *Surgical Endoscopy*. 37(6)
24. Dambrosia, C., Aronoff-Spencer, E., Huang, E.Y., Goldhaber, N.H., Christensen, H., Broderick, R.C., & Appelbaum, L.G., (2023) The Neurophysiology of Intraoperative Error: An EEG Study of Trainee Surgeons during Robotic-Assisted Surgery Simulations. *Frontiers in Neuroergonomics*. 3(1)
25. Ho J, Liu S, Feng Z, Appelbaum LG (2023) Psychomotor and visual skills underlying position specialization in 1352 elite youth baseball players. *PLoS ONE* 18(1): e0278689.
26. Feng, Z., Lochhead, L., Kohn, J.N., and Appelbaum, L.G. (in press) Predictors of batting and pitching performance in the USA Baseball Prospect Development Pipeline. *Sports Biomechanics*

**(b) Papers published in non-peer-reviewed journals**

1. Liu, S., Ferris, L. M., Hilbig, S., Asamo, E., LaRue, J. L., Lyon, D., ... & Appelbaum, L. G. (2020). Dynamic vision training transfers positively to batting performance among collegiate baseball batters. *BioRxiv preprint*.
2. Liu, S., Edmunds, F., Burris, K., & Appelbaum, L. G. (2020). Visual and oculomotor abilities predict professional batting performance. *BioRxiv preprint*.
3. Liu, S., Donaldson, R., Subramaniam, A., Palmer, H., Champion, C., Cox, M., & Appelbaum, L.G. (2020) Skill acquisition and gaze behavior during laparoscopic surgical simulation. *BioRxiv preprint*.
4. Lochhead, L. & Appelbaum, L.G., (2022) Sports Vision Research: Seeing Improvements. In *Optometric Management*

**(c) Presentations**

**i. Presentations at meetings, but not published in Conference Proceedings**

1. Brain Awareness Week public lecture, March-29-2016, Presented by Dr. Greg Appelbaum
2. Duke Neuroscience Program in Research, July-29 2016, Poster presented by Ms. Kelly Vittetoe at the Duke NPR Undergraduate Research Symposium

3. "Sports Vision" Presented by Dr. Greg Appelbaum, Bassett Society Annual Meeting at Duke University, Durham NC. October 8, 2016
4. "Sports Vision Training: A Review" Presented by Dr. Greg Appelbaum, Sports Vision Consortium at Vision Service Providers, National HQ, Sacramento CA., April-11-2017
5. "What is the root of perceptual expertise in athletes and can it be trained" Presented by Dr. Greg Appelbaum, International Sports Vision Association, Annual Meeting, Park City, UT. Feb 9, 2018
6. "Applied Neuroscience to Accelerate Learning" Presented by Dr. Greg Appelbaum, Duke University, Center for Cognitive Neuroscience Seminar Series. Sept 15, 2017.
7. Edmunds, F.R., Liu, S., Appelbaum, L.G. (2019, October) Predictive Assessments in Hitting Performance in Professional Baseball. Poster presentation at the 3rd World Congress of Optometry, Orlando, FL.
8. Liu, S., Folstein, J. R., Appelbaum, L. G., & Tenenbaum, G. (2019, June). Time, control strategy, and working memory capacity affect thinking a recalled experience of choking under pressure in student athletes. Presentation at the annual conference of the North American Society for the Psychology of Sport and Physical Activity (NASPSA), Baltimore, MD.
9. Ferris LM, Liu S., Hilbig S., Port N.L., Applebaum L.G. Enhancing Performance through Vision: Sports Vision Training in Collegiate Baseball Hitters. In: Military Health Systems Readiness Symposium; Kissimmee, FL: Kissimmee, FL; August 2019.
10. Appelbaum, L.G., (2018) Sports Vision Training: A Research Perspective. Presented at the International Sports Vision Association Feb 10, 2019. Park City, UT.
11. Scott M., Ho J., Lichtenstein J., Potter A., Nguyen P., Liu S., & Appelbaum L.G., Predicting baseball performance. Duke Data+ summer program and Rhodes information initiative, Durham, NC. August 2020
12. Liu S., Ferris L.M., Hilbig S., Asamoia E., Port N.L., & Appelbaum L.G., Dynamic vision training transfers positively to batting performance among collegiate baseball batters. Poster at the annual meeting of American College of Sports Medicine (ACSM), San Francisco, CA. June 2020
13. Appelbaum L.G. Noninvasive brain stimulation to improve cognition and mental health. Invited talk at Palo Alto Research Company. 2020
14. Vander Vegt C.B., Appelbaum L.G., Mihalik J.P., Guskiewicz K.M., & Register-Mihalik J.K., Pupillary responses indicate working memory processing differences: Implications for healthy and clinical populations. ACSM, San Francisco, CA. May 2020

15. Vander Vegt C.B., Appelbaum L.G., Mihalik J.P., Guskiewicz K.M., & Register-Mihalik J.K., Pupillary responses indicate neurocognitive processing differences in working memory following concussion. NATA, Atlanta, GA. June 2020
16. Ferris L.M., Liu S., Hilbig S., Port N.L., & Applebaum L.G., Enhancing performance through vision: Sports vision training in collegiate baseball hitters. In Military Health Systems Readiness Symposium, Kissimmee, FL. 2019
17. Edmunds, F.R., Liu, S., & Appelbaum, L.G., Predictive Assessments in hitting performance in professional baseball. Poster presentation at the 3rd World Congress of Optometry, Orlando, FL. October 2019
18. Appelbaum, L.G., Liu, S., Ferris, L.M., Hilbig, S., Asamo, E., LaRue, J.L., Lyon, D., Connolly, K., & Port, N. Dynamic vision training transfers positively to batting performance among collegiate baseball batters. Expertise and Skill Acquisition Network (EASN) Virtual Conference, May 2021
19. Liu, S., Donaldson, R., Subramaniam, A., Palmer, H., Champion, C. D., Cox, M. L., & Appelbaum, L. G. (2021, June). Developing expert gaze pattern in laparoscopic surgery requires more than behavioral training. Verbal presentation at the annual conference of the North American Society for the Psychology of Sport and Physical Activity (NASPSA), Virtual Conference.
20. Appelbaum, L.G., Expediting skills acquisition in surgeons through psychophysiological monitoring and brain stimulation. Boosting Performance: The Mind. The Joint Meeting of Neuroergonomics and NYC Neuromodulation, New York City, July 29, 2022
21. Appelbaum, L.G. & Liu, S. Expediting skill acquisition through psychophysiological monitoring and brain stimulation during surgical simulations. 29th Annual Meeting of the Cognitive Neuroscience Society, San Francisco, CA. April 2022
22. Fogt, N. and Appelbaum, L.G. Research Review: A roadmap to build the evidence base for sports vision. International Sports Vision Association Feb 12, 2022. Kissimmee FL.
23. Appelbaum, L.G. Towards Circuit-Guided, Device-Based Treatment for Mental Health. T32 Biological Psychiatry Fellowship. University of California, San Diego. February 2022.
24. Appelbaum, L.G. Skill acquisition and gaze behaviour during laparoscopic surgical simulation. T32 International Clinical Neuroergonomics. November 2021
25. Appelbaum, L.G., Expediting skills acquisition in surgeons through psychophysiological monitoring and brain stimulation, In, Boosting Performance: The Mind. The Joint Meeting of Neuroergonomics and NYC Neuromodulation, New York City, July 29, 2022

26. Appelbaum, L.G., Vision and on-field performance: do elite athletes have better vision and can training improve performance, In, Boosting Performance: The Body. The Joint Meeting of Neuroergonomics and NYC Neuromodulation, New York City, July 30, 2022
27. Appelbaum, L.G. & Liu, S. Expediting skill acquisition through psychophysiological monitoring and brain stimulation during surgical simulations. 29th Annual Meeting of the Cognitive Neuroscience Society, San Francisco, CA. April 2022
28. Fogt, N. and Appelbaum, L.G. Research Review: A roadmap to build the evidence base for sports vision. International Sports Vision Association Feb 12, 2022. Kissimmee FL.

**ii. Non-Peer-Reviewed Conference Proceeding publications (other than abstracts)**

None

**iii. Peer-Reviewed Conference Proceeding publications (other than abstracts)**

- Burris, K. & Appelbaum, L.G. (2018) Eye on the ball: The relationship between sensorimotor abilities and on-field performance in professional baseball. MIT Sloan Sports Analytics, Boston MA. \*Research paper competition finalist. Presented on Feb 23, 2018.
- Clements, J. M., Kopper, R., Zielinski, D. J., Rao, H., Sommer, M. A., Kirsch, E., Mainsah, B. O., Collins, L. M., and Appelbaum, L. G. (2018) Neurophysiology of visual-motor learning during a simulated marksmanship task in immersive virtual reality. In Proceedings of the 25th IEEE Conference on Virtual Reality and 3D User Interfaces, March 18-22, 2018, Reutlingen, Germany.
- Appelbaum, L.G., Deng, Z-D, Palmer, H., Beynel, L., Watts, A., Young, J.R., Lisanby, S.H., Migaly, J. & Cox, M.L., (2019) Proceedings #2: Transcranial direct current stimulation to enhance laparoscopic technical skill learning: A preregistered randomized controlled trial. Brain Stimulation. 12(2) e57-e59.

**(d) Manuscripts**

**Papers under review in peer-reviewed journals:**

1. Damrosia, C., Huang, E., Goldhaber, N., Christensen, H., Broderick, R., and Appelbaum, L.G., (under review) Objective biometric evaluation of surgical trainees during robot-assisted surgery to assess interoperative error and surgeon performance
2. Lochhead, L., Feng, J., Laby, D.M., and Appelbaum, L.G., (under review) Visual performance and sports: a scoping review

**Technical Reports:** None

**(e) Books**

None

**(f) Honor and Awards**

- 2016 Duke Neuroscience Program in Research - Awarded to Ms. Kelly Vittetoe. This fellowship, awarded through the college of arts and sciences, provided \$2000 for Ms Vittetoe to contribute her summer to research on ARO project.
- MIT Sloan Sports Analytics Research paper competition finalist.

**(g) Title of Patents Disclosed during the reporting period**

None

**(h) Patents Awarded during the reporting period**

None

**(2) Student/Supported Personnel Metrics for this Reporting Period (name, % supported, %Full Time Equivalent (FTE) support provided by this agreement, and total for each category):**

This ARO award supported the training of numerous mentees at both Duke University and the University of California, San Diego who contributed to the scientific progress while also gaining didactic experiences.

**(a) Graduate Students**

David Klemish, Matthew DeLang, Sunith Suresh, Kyle Burris

**(b) Post Doctorates**

Sicong Liu

**(c) Faculty**

Dr. Greg Appelbaum

**(d) Undergraduate Students**

Ben Ramger, Kelly Vittetoe, Rajan Khanna, Maria Naclario, Ted Feng, Jordan Baker, Jessica

Ho, Ashwin Subramaniam, Leo Feng, Edem Asamoah, Erickson Nichols

**(e) Graduating Undergraduate Metrics (funded by this agreement and graduating during this reporting period):**

**i. Number who graduated during this period.**

All undergraduate students have graduated except for Ted Feng, who is currently a senior at UCSD

**(f) Masters Degrees Awarded (Name of each, Total #)**

None

**(g) Ph.D.s Awarded (Name of each, Total #)**

Under the supervision of Dr. Appelbaum, both Matthew DeLang, Doctor of Physical Therapy, and Kyle Burris, 1, PhD in Statistics graduated

**(h) Other Research staff (Name of each, FTE % Supported for each, Total % Supported)**

None

**(3) "Technology transfer" (any specific interactions or developments which would constitute technology transfer of the research results). Examples include patents, initiation of a start-up company based on research results, interactions with industry/Army R&D Laboratories or transfer of information which might impact the development of products.**

As a direct result of the research supported by this ARO award, we opened the Duke Sports Vision Center (<https://dukeeyecenter.duke.edu/divisions/duke-vision-rehabilitation/duke-sports-vision-center>). This center is a joint-venture between the Urbaniak Sports Sciences Institute, the Duke Eye Center, and the Department of Psychiatry and Behavioral Sciences to provide state-of-the-art eye care and neurocognitive interventions to optimize and rehabilitate high performance vision. The center is staffed by a multidisciplinary team including specialists in ophthalmic care, sports vision, cognitive neuroscience, occupational and physical therapy and concussion rehabilitation. This academic-medicine program includes elements of both clinical care and research, measuring vision and performance outcomes to advance the field of sports vision. The clinical and training services provided in this center are the direct result of the successful research and collaborative ties that resulted from this ARO award. Moreover, the interventions used in the center have been tested and/or reviewed under support of this ARO award.

**(4) Scientific Progress and Accomplishments (description should include significant theoretical or experimental advances)**

As listed above, this ARO award supported 26 articles (with 2 more currently under review) and 28 conference presentations. These scientific works have addressed primarily the development and testing of neuroscience-based approaches for optimizing human performance. These articles included several ground-breaking studies, such as

- A first-of-kind pre-registered and placebo-controlled vision-based intervention in collegiate baseball (Liu et al 2020)
- Two of the largest sports cohort studies with over 2000 (Burriss et al 2020) and 1000 (Ho et al 2023) elite athletes
- Several impactful review papers that have averaged over 20 citations per year (Appelbaum and Erickson 2016; Wilkins and Appelbaum 2020; Laby and Appelbaum 2022)
- Two published (and one under review) studies investigating predictive biomarkers of error performance during robot-assisted surgery (Dambrosia et al 2023a and 2023b)
- Studies conducted in collaboration with USA Baseball to test hypotheses about the skills necessary for achievement in elite competition (Ho et al 2023; Feng et al accepted)

Together these studies have advanced the current state of knowledge about high performance while introducing new rigor and unprecedented access to large and important athlete samples

**(5) “Copies of technical reports,” which have not been previously submitted to the ARO, should be submitted concurrently with the Interim Progress Report.**

N/A

**(6) Plans**

The period of performance has ended.