Validation of the Bethesda Eye & Attention Measure for Multimodal Screening and Longitudinal Monitoring of Subacute and Chronic Mild Traumatic Brain Injury

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August 5, 2026

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Disclaimer

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The study protocol was approved by the Naval Medical Center San Diego Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects.

Research data were derived from an approved Naval Medical Center San Diego Institutional Review Board protocol number NMCSD.2020.0045.

Disclosures

- Technology described in this presentation is included in U.S. Patent Application No. 61/779,801, U.S. Patent Application No. 14/773,987, European Patent Application No. 14780396.9, and International Patent Application No. PCT/US2014/022468.
- **Dr. Ettenhofer** is a named inventor on these patents and receives compensation from industry partners related to consultation and commercialization of this technology.
- **Dr. Stephanie Sloley** has no relevant financial or non-financial relationships to disclose relating to the content of this activity.
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- Commercial support was not received for this activity.

Predicting and Tracking Readiness and Recovery in Mild TBI Rehabilitation

- Mild traumatic brain injury (mTBI) can degrade service member health and military readiness,[1-2] but the effects of injury and recovery trajectories can vary widely across individuals.[3-4]
- Multiple sensor-based tools are validated for diagnosis of acute mTBI, but their utility during post-acute phases of recovery remains unclear.[5-7]
- A primary goal of this study was to evaluate sensor-based tools for clinical screening, tracking recovery, and predicting military and operational readiness in service members with subacute and chronic mTBI.
- This presentation will highlight key findings for BrainScope® Concussion Index (CI), Oculogica EyeBOX® (BOX score), and the Bethesda Eye & Attention Measure (BEAM) as predictors of clinical outcomes.

Fusion-Virtual Reality (VR)+ Study: Methods

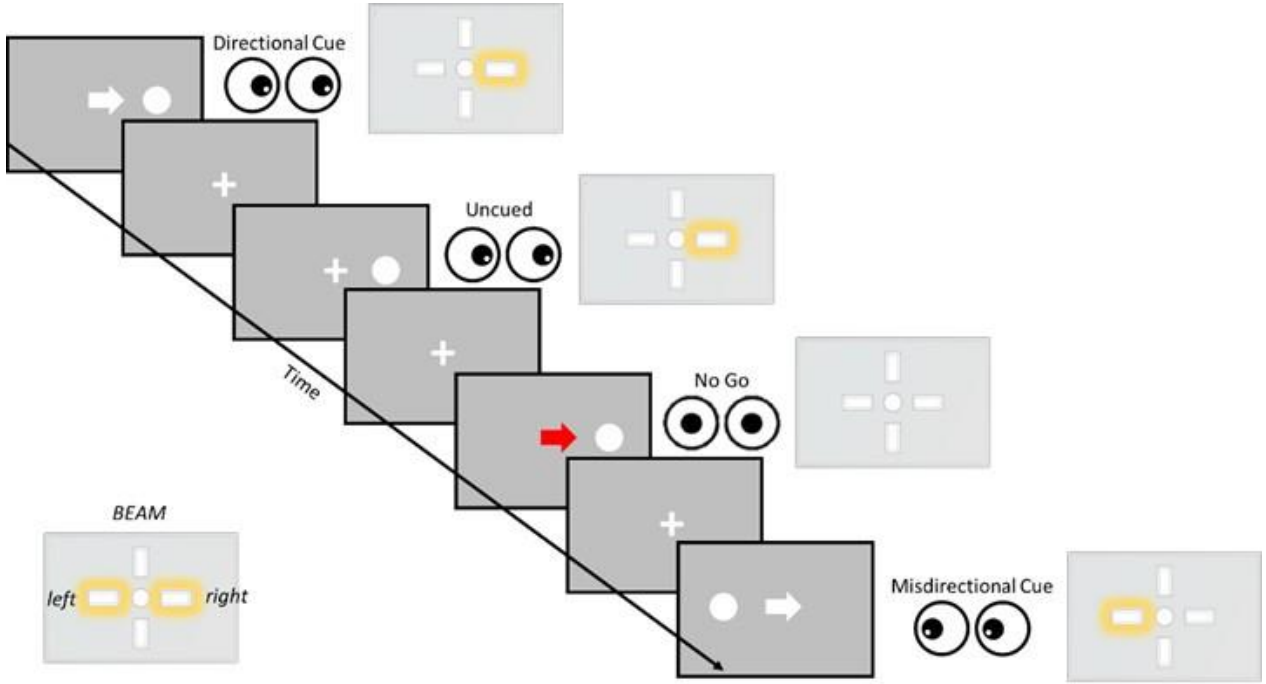
- Design
  - Longitudinal (8-12 weeks)

Group	Study Timepoint			
	Initial	Intermediate 1	Intermediate 2	Final
Subacute mTBI	29	29	N/A	26
Chronic mTBI	38	37	33	36
Control	36	34	N/A	32

Table 1. Participant Accrual (n) by Group and Study Timepoint

- Sites
  - Naval Medical Center San Diego (NMCSD) + Naval Health Research Center
- Participants
  - 103 active duty service members aged 18-50 years (y) with weapons training
    - 29 subacute mTBI (symptomatic 7 - 90 days [d] post-injury)
    - 38 chronic mTBI (symptomatic 90 d - 10 y post-injury)
    - 36 controls (no history of mTBI)
- Primary measures
  - Clinical Screening Tools
    - BrainScope® Concussion Index
    - Oculogica EyeBOX®
    - BEAM: saccadic inhibition errors, latency and variability, manual latency and variability
  - Outcomes
    - Neuropsychological testing
    - Vestibular and balance performance
    - Self-report measures
    - Simulated operational performance: VR foot patrol
- Primary analyses
  - Predict track outcomes from screening tools using linear mixed models controlling for age

Neurocognitive Eye Tracking Utilizing BEAM



INSTRUCTIONS

"Look at the circle and press the correct button as quickly as you can. For circles on the LEFT, press the LEFT button. For circles on the RIGHT, press the RIGHT button.

However, if you see a RED arrow, don't look at the circle, and don't press the button."

Image credit: All images generated by presentation authors.

Simulating Operational Performance: VR Foot Patrol

Photo courtesy of Naval Health Research Center

VR Foot Patrol Task Sets

1. Go/No-Go
2. Target Discrimination
3. Working Memory (WM)
4. WM + Radio Comms

Operational Metrics

- *Shooting:*
    1. *Accuracy*
    2. *Speed*
    3. *Consistency*

- *Eye tracking:*
    4. *Inhibition (Distractibility)*

Results: Predicting Clinical Outcomes (Patient Stratification)

Effect sizes shown (partial η^2)

Small ≥.02 | Medium ≥.06 | Large ≥.14

	Self-Reported Symptoms				Sleep		Vestibular & Mobility					Cognition	Activity
	NSI	PHQ8	PCL5	HIT6	ISI	PSQI	DHI[a]	VVAS[a]	SOTɣ	CB&Mɣ	VOMS[a]	Global T	PRA
Oculogica EyeBOX®[a]		0.05*		0.08**		0.10**	0.11***	0.09**	0.06*	0.06*			0.06*
BrainScope® CIɣ	0.07**		0.04*	0.14***		0.08**	0.08**	0.05*	0.07*	0.07*	0.06*	0.08**	0.08**
Global Cognitive Performance	0.11***	0.13***	0.12***	0.07**	0.05*	0.08**	0.11**	0.07**	0.10**	0.18***		--	0.12***
BEAM Saccadic Inhibition Errors‡				0.07**		0.08**	0.09**	0.11***	0.13***			0.09**	0.06*
BEAM Saccadic Variability				0.06*			0.04*	0.05*	0.07*	0.05*	0.07*	0.13***	0.09**
BEAM Manual Variability	0.05*	0.05*		0.07**			0.08**	0.06*	0.06*	0.06*		0.13***	0.17***
BEAM Manual RT[a]			0.04*	0.06*		0.06**	0.09**	0.07**				0.15***	0.06*

Notes. [a] log transformed. ɣ reflected log transformed. ‡ square root transformed. NSI, Neurobehavioral Symptom Inventory; PHQ8, 8-item Patient Health Questionnaire; PCL5, Posttraumatic Stress Disorder (PTSD) Checklist for DSM-5; HIT6, 6-item Headache Impact Test; ISI, Insomnia Severity Index; PSQI, Pittsburgh Sleep Quality Index; DHI, Dizziness Handicap Inventory; VVAS, Visual Vertigo Analogue Scale; SOT, Sensory Organization Test; CB&M, Community Balance and Mobility Scale; VOMS, Vestibular/Ocular Motor Screening; Global T, composite score of conventional neuropsychological tests; PRA, Progressive Return to Activity; BrainScope® CI, Concussion Index; BEAM, Bethesda Eye & Attention Measure; RT, response time. Only $p \leq .05$ is shown. * p < .05. ** p < .01. *** p < .001. All analyses controlled for age.

Results: Tracking Change Over Time (Clinical Monitoring)

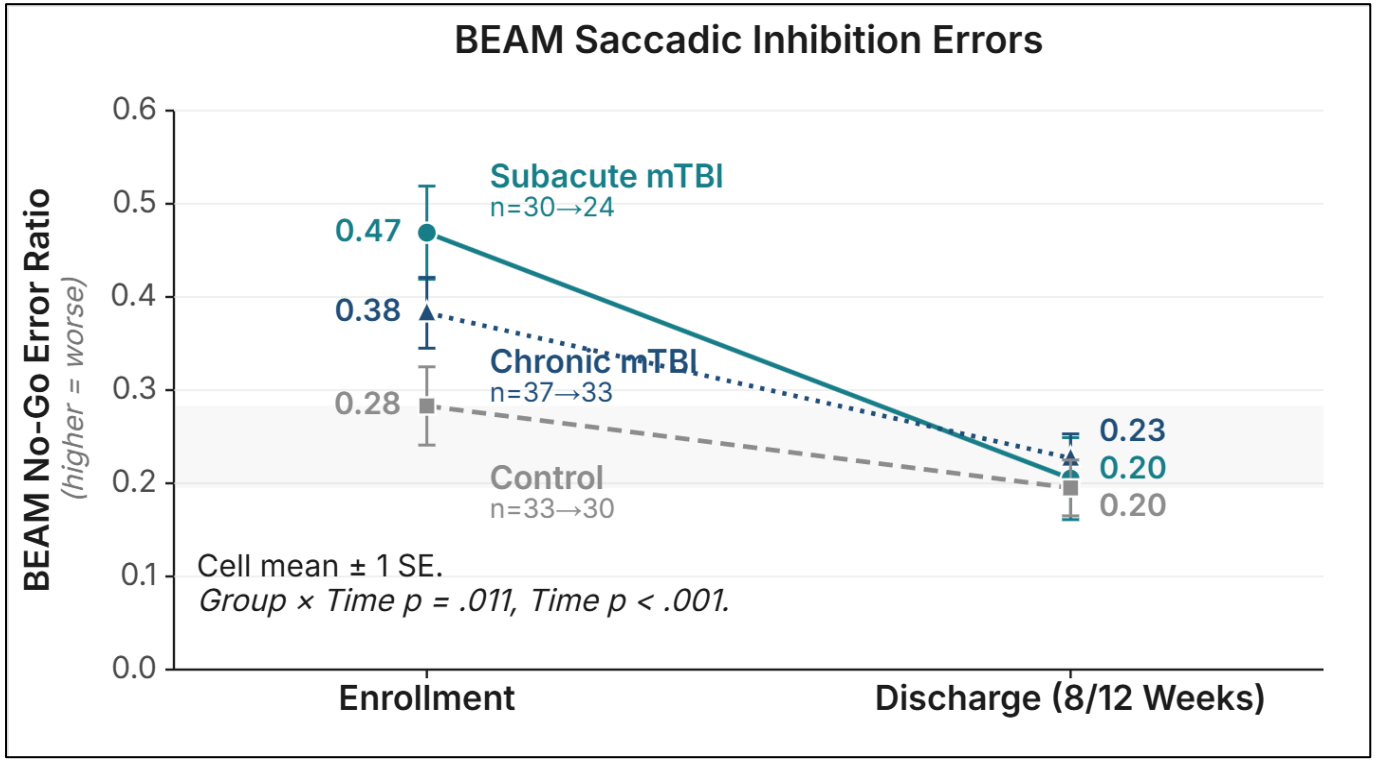
Effect sizes shown (partial η^2)

Small ≥.02 | Medium ≥.06 | Large ≥.14

	Self-Reported Symptoms				Sleep		Vestibular & Mobility					Cognition	Activity
	NSI	PHQ8	PCL5	HIT6	ISI	PSQI	DHI[a]	VVAS[a]	SOT[ɣ]	CB&M[ɣ]	VOMS[a]	Global T	PRA
Oculogica EyeBOX®[a]									0.23***				
BrainScope® CI[ɣ]					0.02*								
Global Cognitive Performance	0.07***									0.08*		--	
BEAM Saccadic Inhibition Errors‡	0.07*	0.07*	0.06*										
BEAM Saccadic Variability										0.13**			
BEAM Manual Variability													
BEAM Manual RT[a]	0.05*										0.08*		

Notes. [a] log transformed. [ɣ] reflected log transformed. ‡ square root transformed. NSI, Neurobehavioral Symptom Inventory; PHQ8, 8-item Patient Health Questionnaire; PCL5, Posttraumatic Stress Disorder (PTSD) Checklist for DSM-5; HIT6, 6-item Headache Impact Test; ISI, Insomnia Severity Index; PSQI, Pittsburgh Sleep Quality Index; DHI, Dizziness Handicap Inventory; VVAS, Visual Vertigo Analogue Scale; SOT, Sensory Organization Test; CB&M, Community Balance and Mobility Scale; VOMS, Vestibular/Ocular Motor Screening; Global T, composite score of conventional neuropsychological tests; PRA, Progressive Return to Activity; BrainScope® CI, Concussion Index; BEAM, Bethesda Eye & Attention Measure; RT, response time. Only $p \leq .05$ is shown. * p < .05. ** p < .01. *** p < .001. All analyses controlled for age.

Results: Saccadic Inhibition Improves Across mTBI Recovery and Rehabilitation



At enrollment, the subacute mTBI group made more saccadic inhibition errors than controls (p = .005).

Notes. SE, Standard Error.

Results: BEAM Predicts Simulated Operational Performance

VR Foot Patrol: Task Conditions and Metrics

Effect sizes shown (partial η^2)
Small ≥.02 Medium ≥.06 Large ≥.14

	Go/No-Go			Target Discrimination			Working Memory			Working Memory + Comms		
	Sac Inhib	Shot SD	Shot RT	Accuracy	Shot SD	Shot RT	Accuracy	Shot SD	Shot RT	Accuracy	Shot SD	Shot RT
Oculogica EyeBOX®[a]												
BrainScope® CI[ɣ]												
Global Cognitive Performance	0.07*				0.12***	0.06*		0.15***		0.10*	0.10**	0.05*
BEAM Saccadic Inhibition Errors‡	0.22***		0.06*	0.12**	0.05*	0.09**	0.07*	0.10**	0.08*	0.08*	0.08*	0.09*
BEAM Saccadic Variability	0.16***	0.06*			0.14***			0.08**			0.07**	
BEAM Manual Variability	0.11***	0.14***	0.07*		0.18***	0.06*		0.15***	0.06*		0.10**	0.07*
BEAM Manual RT[a]	0.05*		0.15***		0.07*	0.10**		0.08**	0.18***		0.06*	0.14**

Notes. [a] log transformed. [ɣ] reflected log transformed. ‡ square root transformed. SD, standard deviation; RT, response time; Comms, Radio Communications; BrainScope® CI, Concussion Index; BEAM, Bethesda Eye & Attention Measure. Only $p \leq .05$ is shown. * p < .05. ** p < .01. *** p < .001. All analyses controlled for age.

Summary and Implications

- The Fusion VR+ Study was conducted to evaluate multimodal predictors of clinical outcomes and simulated operational performance in service members with subacute and chronic mTBI.
- BrainScope® CI, Oculogica EyeBOX®, and BEAM were all successful in stratifying individuals based on broad clinical outcomes.
- BEAM metrics successfully tracked clinical recovery over time.
- Similarly, BEAM metrics uniquely predicted shot speed, consistency, accuracy, and visual distractibility on the VR foot patrol.
- These results support continued advancement of neurocognitive eye tracking as a sensitive and objective index of clinical recovery and operational readiness after mTBI.

Future Directions: Deploying BEAM on Operational Extended Reality (XR)

- Head-worn XR is under development for operational use:
  - Units such as U.S. Army Soldier Borne Mission Command (SBMC)
  - Built-in displays, eye tracking, and processing
- The XR platforms provide a promising avenue for deployment of sensor-based assessment technology like BEAM.
- Embedding validated tools like BEAM in operational hardware could bring objective brain-health screening and recovery monitoring to the point of need.
- Additional work is needed to expand sensor-based brain assessment capabilities across clinical and operational environments.

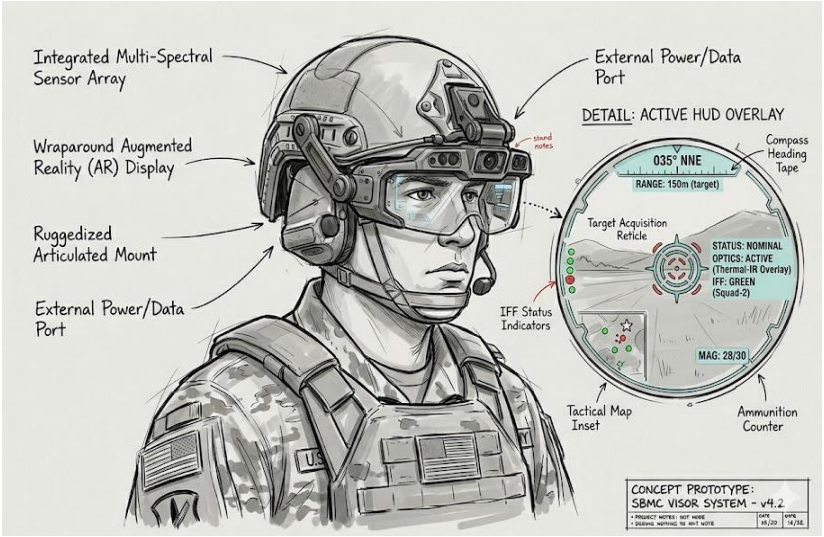


Image generated by presentation authors

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Acknowledgments

- Naval Medical Center San Diego
  - Mark Ettenhofer, PhD (PI, study lead)
  - Lars Hungerford, PhD (site PI)
  - Sarah Gimbel, PhD
  - Dawn Bodell, DPT
  - Angelica Aguirre, MA
  - Sean Molnar, MA
  - Julianna Dunivin, MA
- Naval Health Research Center
  - Pinata Sessoms, PhD (site PI)
  - Weimin Zheng, PhD
  - Jacob VanDehy, MS
  - Hedaya Rizeq, MS
  - Carlie Daquino, BA
- Grant Support – CDMRP
  - W81XWH-20-2-0060
- Institutional Support
  - TBI Center of Excellence, Defense Health Agency

Questions/Comments?

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