

Virtual Reality Balance Assessment Detects mTBI-Related Deficits Missed by Gold-Standard Clinical Testing

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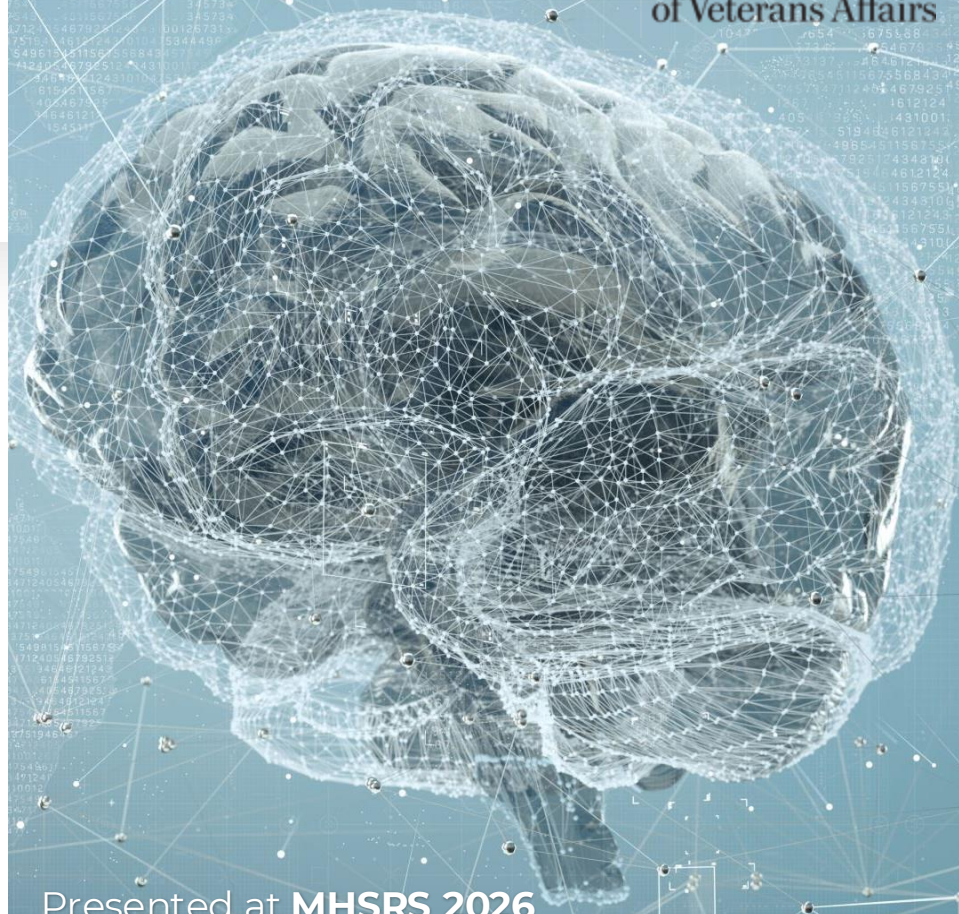
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U.S. Department
of Veterans Affairs



Presented at **MHSRS 2026**

Aug 03, 2026

Congressionally Directed Medical Research Programs

CDMRP

Department of Defense



Award Number(s):

JWMRP

W81XWH21C0048

Disclosure

- W. Geoffrey Wright and Greg Teodoro have equity with UprightVR, which produces balance assessment equipment.
- No other authors have disclosed relevant, real, or apparent personal or professional financial relationships with proprietary entities that produce healthcare good and services.



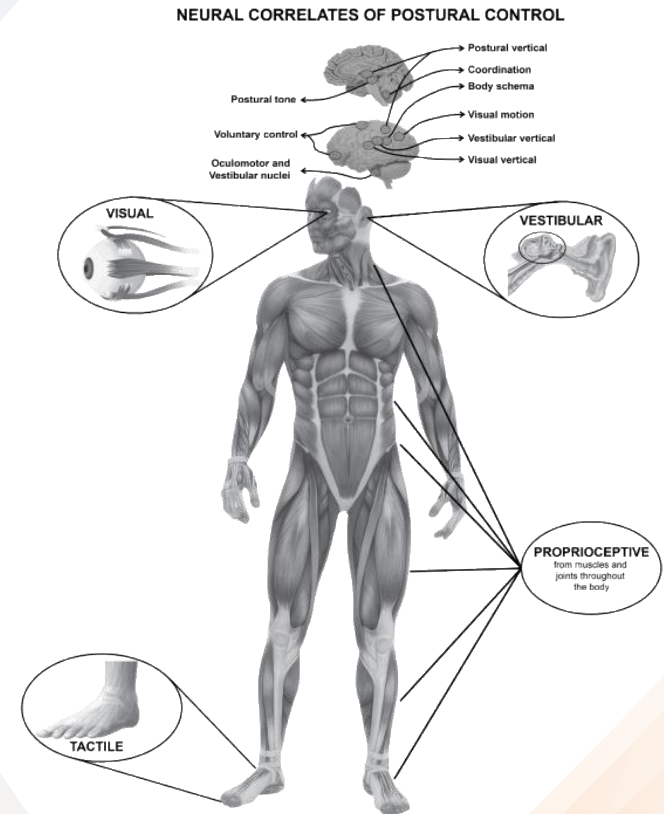
Impact of concussion on Balance, Vestibular, & Oculomotor Function

- Changes in postural control have long been used as a marker for brain injury because of the complexity of the neural processing underlying this motor behavior
 - Persistent balance deficits reduce readiness
- The most common physical sequelae of mTBI are dizziness, vestibular, and visual problems
 - Chronic mTBI often appears “normal”
- Existing tests lack sensitivity
- Need portable objective biomarkers



Balance is fundamentally a problem of sensory integration — not simply motor output

- Peripheral sensory inputs
 - Visual input
 - Somatosensory input
 - Vestibular input
- Central integration
 - Numerous brain regions involved in balance



Can portable VR do as well – or better than current “Gold Standard”?



Neurocom SOT

- Strengths
 - Accurate
 - Validated
- Limitations
 - Expensive
 - Large
 - Laboratory only
 - Uncertain sensitivity in chronic mTBI



VR-based alternative

- Strengths
 - Portability
 - Usability/Ease-of-use
 - Affordability
 - Flexibility
 - Accuracy – Sensitivity and Specificity
- Open questions
 - Validate on military and veteran mTBI detection



Virtual Reality Sensory Integration in Balance (VRSIB)

- Head-centered sway measurement
 - Total sway area (95% Sway ellipse – PCA)
 - Sway velocity
 - Sway variability (AP and ML STD)
- 8-minute balance assessment
- Eight conditions (4 Visual x 2 Surface)
 1. Eyes Open - Firm
 2. Eyes Closed - Firm
 3. Sway-Referenced - Firm
 4. Spin - Firm
 5. Eyes Open - Foam
 6. Eyes Closed - Foam
 7. Sway-Referenced - Foam
 8. Spin - Foam



Study Design

- Veterans (n=71) recruited from the Philadelphia VA Hospital
 - 54 with and 17 without of a history of mTBI
 - 24 mTBI Hx only, 30 mTBI Hx + PTSD, 6 PTSD only, 11 Healthy
 - Age: Mean 39 ± 8.3 yrs, Range 23-53 yrs
 - M: n=45, F: n=26
- Protocol
 - Balance assessed - gold-standard SOT and novel VRSIB
 - Clinical measures - PCL-5, SCAT5, MACE
- Statistical Analyses
 - Criterion-measure validity
 - Pearson/Spearman correlational analysis performed
 - Construct-validity
 - Mixed model rmANOVA and ANCOVA
 - “Known-groups” – ROC Analysis

Criterion Validity

VRSIB vs. SOT

Pearson Correlations

Composite Scores

$r = .601, p < 0.001$

EO-Stable

$r = .652, p < 0.001$

EC-Stable

$r = .794, p < 0.001$

SR-Stable

$r = .481, p < 0.001$

EO-Unstable

$r = .506, p < 0.001$

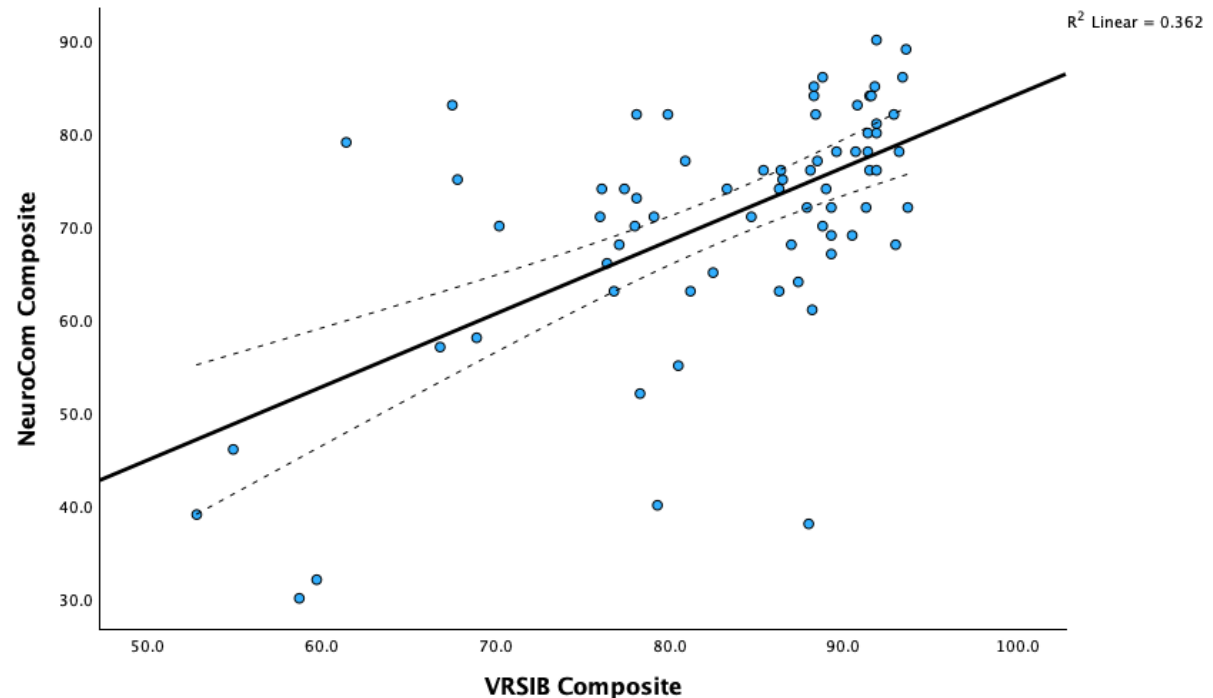
EC-Unstable

$r = .526, p < 0.001$

SR-Unstable

$r = .437, p < 0.001$

VRSIB and SOT show significant correlations across all matched conditions



Head-sway and Center of Pressure metrics detect different aspects of postural stability

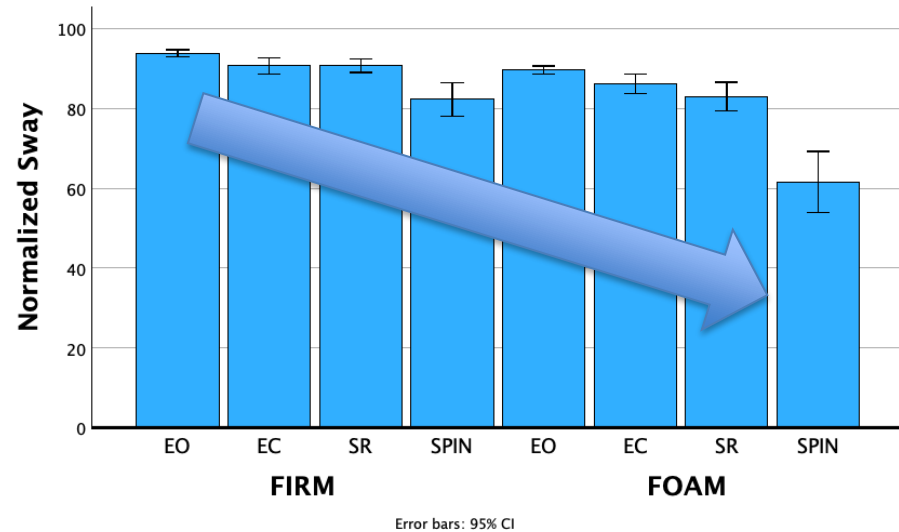
VRSIB and SOT

Construct validity

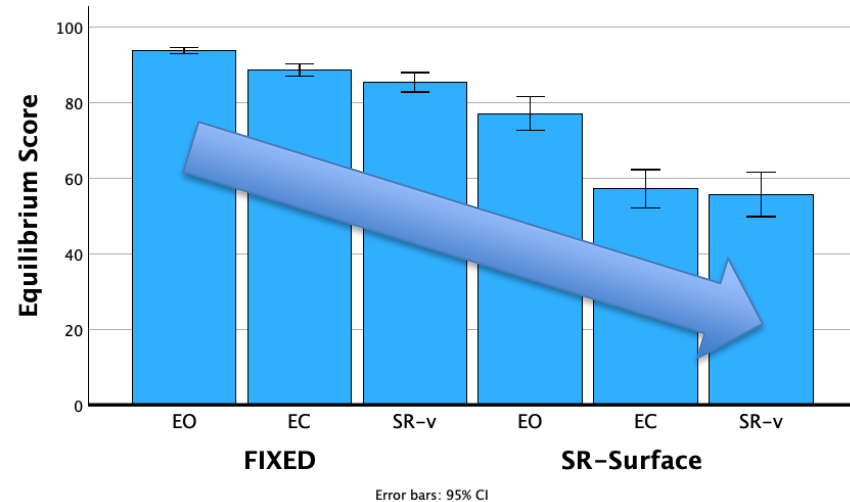
Balance score gets worse as sensory availability and/or reliability decreases

- Each condition worse than the baseline ($p < 0.001$)

VRSIB - Stability decreases with postural challenge



SOT - Stability decreases with postural challenge



Mixed model ANOVA

Between group

Compare veterans with and without history of mTBI

VRSIB

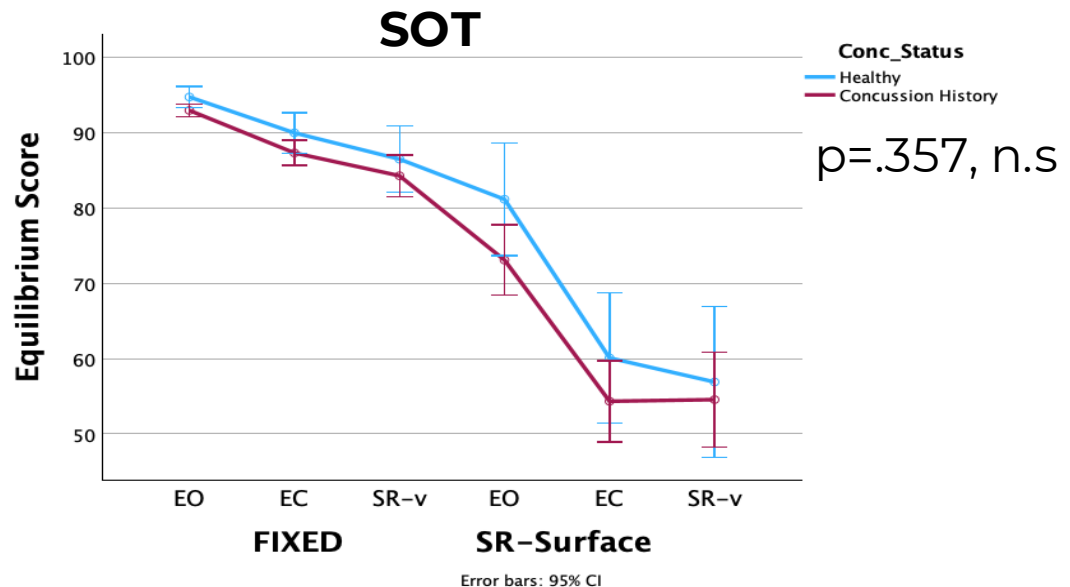
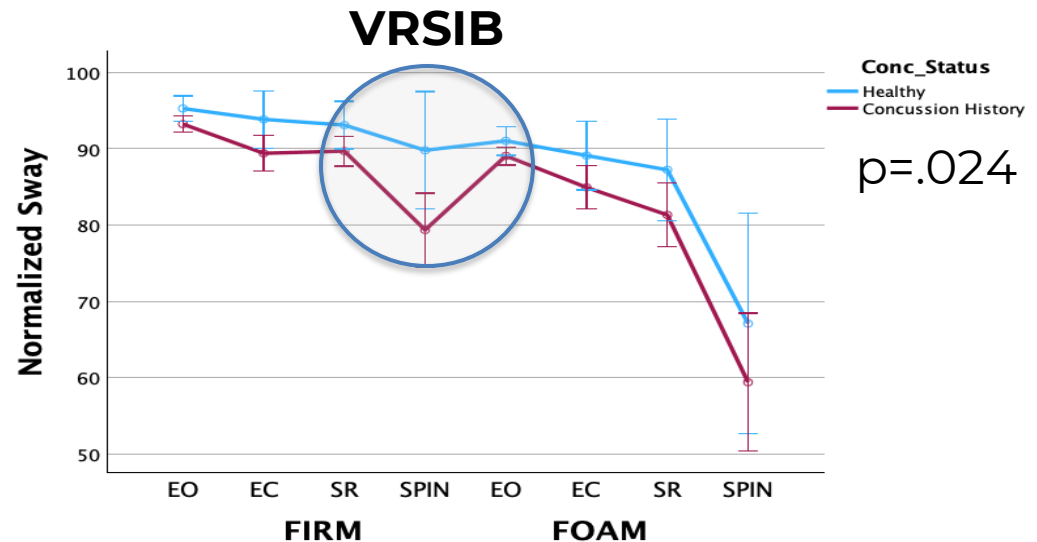
With vs without mTBI Hx
 $F=5.366$, $p=.024$

EO-Firm - $p=0.030$
EC-Firm - $p=0.024$
SPIN-Firm - $p=0.016$
EC-Foam - $p=0.032$
SR-Foam - $p=0.044$

SOT

With vs without mTBI
 $F=0.859$, $p=.357$, n.s.
Does not detect mTBI

VRSIB detects remote history of mTBI in Veterans - SOT does not



ROC analysis

Sensitivity

Compare veterans with and without history of mTBI

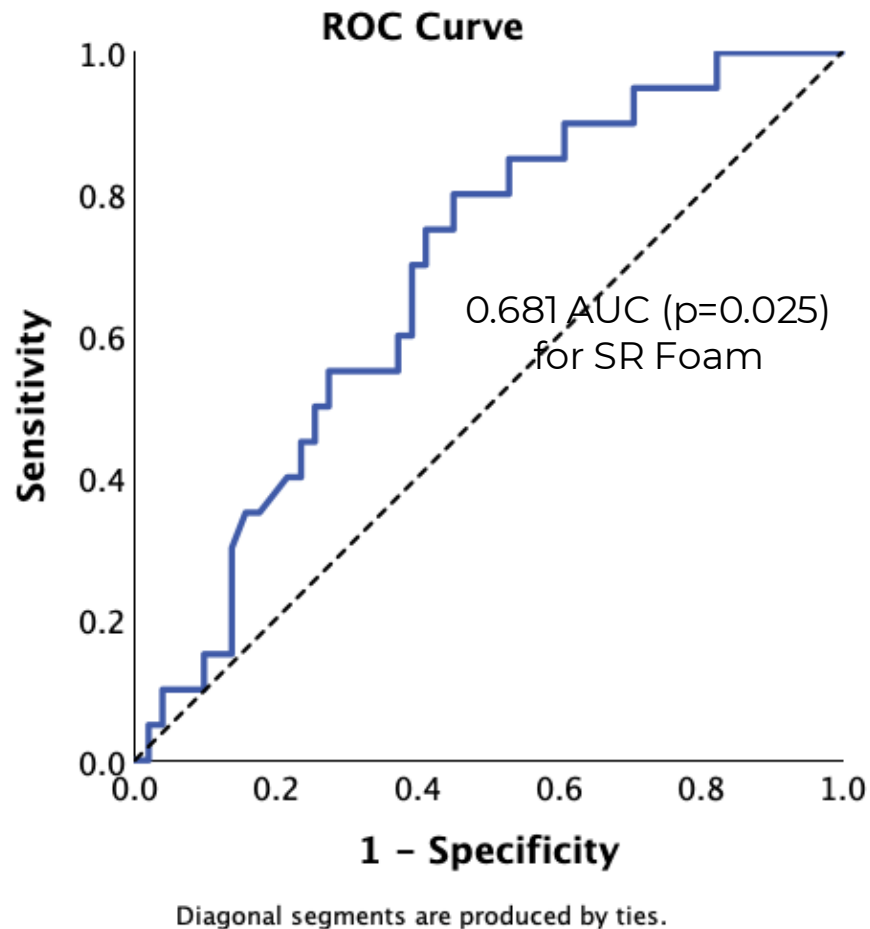
VRSIB

SPIN-Firm	0.64 AUC
EO-Foam	0.66 AUC
SR-Foam	0.68 AUC

SOT

All $p > 0.05$, n.s.
Does not detect mTBI

VRSIB Sensory conflict most sensitive



*Visual-Vestibular Sensory Mismatches
are critical*

ANCOVA analysis

Clinical assessments as predictors of balance (VRSIB)

Compare veterans with and without history of mTBI with cofounders considered

Covariate variables

- **Concussion Signs and Symptoms**

- SCAT5 # of Symptoms, $F=2.80$, $p=.099$, n.s.
- SCAT5 Symptom Severity, $F=1.05$, $p=.309$, n.s.
- mTBI history, $p=.36$, n.s.



- **PTSD not a moderating factor**

- PCL-5 score $F=2.08$, $p=.15$, n.s.
- mTBI history, $p=.25$, n.s.



- **Vestibular symptoms**

- VOMS Total score $F=.795$, $p=.376$, n.s.
- VOMS VMS score $F=.092$, $p=.044$
- mTBI history, $p=.29$, n.s.



- **Age is a moderating factor**

- Age $F=6.707$, $p=.012$
- mTBI history, $p=.045$



Clinical Impact for Military and Veterans



- Veteran and military populations suffer from unique pathologies with complex comorbid sequelae following TBI and combat exposure
 - Overlapping physiogenic and psychogenic etiologies
- Portable VR-based device that is accurate, accessible, and easy to use will provide...
 - Objective assessment
 - Earlier detection
 - Improved clinical decision-making
 - Support return-to-duty decisions and readiness
 - Ability to monitor recovery
 - Markers for when pre-injury functionality and community reintegration are reached



Developmental Status of the Technology

- Balance assessment device has a commercial version validated (TRL-9)
 - FDA registration completed in Dec 2022
 - Class 1 PMA exempt
 - HIPAA compliant and Cybersecure (NIST 800-53 Low Baseline) database
- Validated against gold-standard for reliability and accuracy
 - Fall-risk detection in a geriatric population
 - mTBI and concomitant vestibular deficit testing



Take-home Messages and Next Steps



VR detected chronic mTBI balance deficits missed by NeuroCom.

VRSIB addresses a critical diagnostic gap in military medicine, by identifying impairments missed by traditional tools.



VR-SIB provides valid assessment of sensory integration.

Specifically focuses on visual-vestibular deficits in mTBI



Portable immersive VR has strong potential as an operational digital biomarker for military medicine.

Sensitive to post-acute and lifetime mTBI
More accurate than BESS, cheaper than SOT
Portable and field-deployable



Use VRSIB outcomes to guide targeted treatment

VR recovery modules have been designed to treat specific deficits
Conduct clinical trials to validate efficacy



Acknowledgements

Temple University

- Greg Teodoro, MS
- Shirin Hussain, PhD
- Maddy Guidash, MS
- Jingwei Wu, PhD
- Lei Ma, DPT, PhD



Veterans Affairs

- Keith Robinson, MD
- Randy Swanson, DO, PhD
- Kelly Heath, MD
- Kerri Butler, MSPT
- Rose Biester, PhD
- Will McBride, MD



U.S. Department
of Veterans Affairs



USCG



USN



Funding:

CDMRP, W81XWH-20-JWMRP, W81XWH-13-C-0189

VA SpiRE

ARL – Army Research Lab

PA Cure, Temple OVPR

BSF 2023319 and 2019222



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