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False-Positive Rates and Associated Risk Factors on the Vestibular-Ocular Motor Screening and Modified Balance Error Scoring System in US Military Personnel

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Context: In 2018, the US military developed the Military Acute Concussion Evaluation-2 (MACE-2) to inform the acute evaluation of mild traumatic brain injury (mTBI). However, researchers have yet to investigate false-positive rates for components of the MACE-2, including the Vestibular-Ocular Motor Screening (VOMS) and modified Balance Error Scoring System (mBESS), in military personnel.

Objective: To examine factors associated with false-positive results on the VOMS and mBESS in US Army Special Operations Command (USASOC) personnel.

Design: Cross-sectional study.

Setting: Military medical clinic.

Patients or Other Participants: A total of 416 healthy USASOC personnel completed the medical history, VOMS, and mBESS evaluations.

Main Outcome Measure(s): False-positive rates for the VOMS ($\geq$2 on VOMS symptom items, $>$5 cm for near point of convergence [NPC] distance) and mBESS (total score $>$4) were determined using χ^2 analyses and independent-samples *t* tests. Multivariable logistic regressions (LRs) with adjusted odds ratios (aORs) were performed to identify risk factors for false-positive results on the VOMS and mBESS. The VOMS item false-positive rates ranged from 10.6% (smooth pursuits) to 17.5% (NPC). The mBESS total score false-positive rate was 36.5%.

Results: The multivariable LR model supported 3 significant predictors of VOMS false-positives, age (aOR = 1.07; 95% CI = 1.02, 1.12; *P* = .007), migraine history (aOR = 2.49; 95% CI = 1.29, 4.81; *P* = .007), and motion sickness history (aOR = 2.46; 95% CI = 1.34, 4.50; *P* = .004). Only a history of motion sickness was a significant predictor of mBESS false-positive findings (aOR = 2.34; 95% CI = 1.34, 4.05; *P* = .002).

Conclusions: False-positive rates across VOMS items were low and associated with age and a history of mTBI, migraine, or motion sickness. False-positive results for the mBESS total score were higher (36.5%) and associated only with a history of motion sickness. These risk factors for false-positive findings should be considered when administering and interpreting VOMS and mBESS components of the MACE-2 in this population.

Key Words: Military Acute Concussion Evaluation-2, mild traumatic brain injury, concussion

Key Points

- Vestibular-Ocular Motor Screen false-positive rates were acceptably low in this population and were associated with age and a history of mild traumatic brain injury, migraine, or motion sickness.
- False-positives on the modified Balance Error Scoring System total score were higher (36.5%) but were associated only with a history of motion sickness.
- Military medical personnel should consider the factors associated with false-positive rates when administering and interpreting Vestibular-Ocular Motor Screen and modified Balance Error Scoring System results in this at-risk population.

Mild traumatic brain injury (mTBI) affects approximately 18 000 military personnel each year.[1] Identifying military personnel with mTBIs is challenging due to the heterogeneous nature of the injury, which is characterized by myriad symptoms, impairments, and functional effects, such as headache, vestibular dysfunction, and mental health concerns, respectively,[2] The military operational milieu presents additional challenges in identifying patients with mTBI in the austere, often remote environments of combat and training, where access to medical professionals may be limited. To address these challenges, in 2018, the US military developed the Military Acute Concussion Evaluation-2 (MACE-2) in hopes of informing earlier diagnosis and treatment of mTBI among US military personnel. The MACE-2 includes an assessment of concussion "red flags" (eg, loss of consciousness, double vision, vomiting); concussion screening, which includes symptom identification, brief cognitive (eg, concentration and immediate or delayed memory), and neurologic (eg, speech fluency, grip strength, balance, gait, and pupillary response) examinations; and an adapted version of the Vestibular-Ocular Motor Screening (VOMS) tool. The VOMS tool, which was designed to provide a brief (5-minute) screen of vestibular and oculomotor symptoms and impairments that requires minimal equipment (ie, a tape measure and fixation stick),[3] was not available when the original MACE was developed.[4]

The VOMS tool assesses symptom provocation via 7 vestibular and oculomotor components: (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4) near point convergence (NPC), (5) horizontal vestibular-ocular reflex (VOR), (6) vertical VOR, and (7) visual motion sensitivity (VMS). The tool also includes average NPC distance (cm) across 3 trials. Previous researchers[5] indicated that the VOMS was accurate in identifying 89% of concussions. Other authors showed that the VOMS had prognostic value in predicting recovery after concussion[6] and that healthy, uninjured collegiate student-athletes had low (11%) false-positive rates across the VOMS components.[7] However, when false-positives did occur, they were associated with factors such as being female and a history of motion sickness.[7] Military-specific factors, such as the total time deployed and years of experience in the military, may influence VOMS scores in healthy, uninjured military personnel because vestibular dysfunction can progress over time as a result of military-specific exposures such as blasts or explosions.[8] We needed to evaluate the performance of the VOMS in healthy, uninjured military personnel to create the framework for its use without a baseline examination in personnel with mTBI.

Another component of the MACE-2 is a reduced version of the modified Balance Error Scoring System (mBESS), which measures vestibulo-spinal function.[9] This test is considered a pivotal, acute, multidomain assessment of mTBI, with impairments in performance evident up to 5 days postinjury.[10] However, the reliability of the measure in civilian athletes has been questioned.[11–13] A high rate of false-positives was a concern among researchers and clinicians,[14] but the false-positive rate in this population had not yet been determined. Understanding the rate of false positives and associated risk factors may yield critical information for the clinician administering the MACE-2.

The primary purpose of our study was to examine false-positive rates on the VOMS and mBESS components of the MACE-2 in healthy US Army Special Operations Command (USASOC) personnel. We expected that the VOMS and mBESS would have low rates of false-positives (<20%) in this population. A secondary purpose of this study was to evaluate the association of possible risk factors for false-positive results on the VOMS and mBESS in this population, including demographics (age, sex, ethnicity, race, military occupation specialty [MOS], length of military service, and total time deployed) and medical history (mental health, mTBI, migraine, and motion sickness). Given the association between these risk factors and false-positives in athletes, as well as the greater rate of vestibular dysfunction with increased mTBI history and military-type occupational exposures,[7,8] we expected that a history of mTBI, migraine, and motion sickness, along with total time deployed and years of military service, would be associated with false-positive results in the sample population. We also hypothesized that the factors associated with false-positives would be similar for the VOMS and mBESS.

METHODS

Design and Participants

We conducted a cross-sectional design involving prospectively enrolled participants. We enrolled 418 active duty USASOC military personnel from a single site between March 2018 and January 2020. A total of 416/418 eligible USASOC personnel consented to be in the study, and 399/418 provided complete VOMS and mBESS data. Inclusion criteria were current active duty USASOC personnel aged 18 to 40 years with normal or corrected 20/20 vision. Participants were excluded if they had a history of vestibular (eg, benign paroxysmal positional vertigo, Ménèiere disease) or neurologic (eg, seizure disorder, stroke) disorder, previous moderate-to-severe TBI, or an mTBI within the previous 3 months.

Measures

Demographics and Medical History. Participants self-reported demographics: age, sex, ethnicity, race, MOS, length of time in military service (years and months), and length of time deployed (months). Participants also self-reported medical history consisting of mental health, migraine, and motion sickness history; mTBI history, including the number, type, and most recent date; and current medications.

Vestibular-Ocular Motor Screening. The VOMS is a reliable tool in this population and was used to assess vestibular and oculomotor symptoms and impairment.[15] The VOMS consists of 7 brief assessments in the following domains: (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4) NPC, (5) horizontal VOR, (6) vertical VOR, and (7) VMS.[5] Before administration of the VOMS, participants are asked to self-report their baseline severity of dizziness, headache, nausea, and fogginess on a scale of 0 (*none*) to 10 (*severe*).[5] After each item is administered, he or she is asked to rate each symptom again on the same 0 to 10 scale. The NPC is assessed by both symptom report and 3 NPC measurements from which an average NPC value is derived.[5] Clinical cutoffs for the VOMS are a symptom provocation score of $\geq$2 on any item and an NPC distance of $\geq$5 cm. The VOMS takes approximately 5 to 7 minutes to administer.

Modified Balance Error Scoring System. The mBESS was used to measure postural stability. The mBESS consists of static balance performed during 3 conditions: (1) double-legged stance (feet are side by side), (2) tandem stance, and (3) single-legged stance on the nondominant leg.[16] For each condition, participants are instructed to stay as still as possible for 20 seconds while holding their hands on their iliac crests with eyes closed. During the 20 seconds, a trained observer records balance errors, including lifting the hands off the iliac crests, opening the eyes, stepping, stumbling, falling, lifting the heel or foot, moving the hips into >30° of flexion or abduction, or remaining out of the testing position for >5 seconds. Each error is recorded as 1 point, with a maximum of 10 errors per condition or 30 points total across all mBESS conditions. Higher scores

Table 1. Risk Factors Among US Army Special Operations Command Personnel With Normal or False-Positive Vestibular-Ocular Motor Screening Score (N = 415)

	Vestibular-Ocular Motor Screening Score	
Risk Factor	Normal (n = 324)	False-Positive (n = 91)
Continuous, mean ± SD		
Age, y	28.0 ± 5.4	30.1 ± 6.1
Military service, y	6.7 ± 5.0	8.6 ± 5.7
Total time deployed, mo	10.1 ± 14.2	14.7 ± 16.9
Categorical, No. (%)		
Sex, female	35 (10.8)	9 (9.9)
Military occupation specialty	85 (26.2)	21 (23.1)
Mild traumatic brain injury history[a]	97 (29.9)	41 (45.1)
Migraine history[a]	28 (8.6)	22 (24.2)
Motion sickness history[a]	39 (12.0)	23 (25.3)

[a] $P < .05$.

Table 2. Risk Factors Among US Army Special Operations Command Personnel With Normal or False-Positive Modified Balance Error Scoring System Total Score >4 (N = 415)

	Modified Balance Error Scoring System Total Score >4	
Risk Factor	Normal (n = 263)	False-Positive (n = 151)
Continuous, mean ± SD		
Age, y	28.4 ± 5.4	28.5 ± 6.1
Military service, y	7.1 ± 5.1	7.1 ± 5.4
Total time deployed, mo	10.7 ± 15.0	11.4 ± 14.5
Categorical, No. (%)		
Sex, female	29 (11.0)	15 (9.9)
Military occupation specialty	70 (26.6)	35 (23.2)
History of mild traumatic brain injury	88 (33.5)	49 (32.5)
History of migraine	31 (11.8)	19 (12.6)
History of motion sickness[a]	29 (11.0)	33 (21.9)

[a] $P = .003$.

reflect worse balance performance. The mBESS takes approximately 4 to 5 minutes to administer.

Procedures

The study was approved by the University of Pittsburgh Institutional Review Board (No. PRO15090054) and the US Army Medical Research and Development Human Research Protection Office. The research staff informed all study participants of the risks and benefits of participation, and participants provided written, informed consent before the study began. Trained study personnel collected demographic data and then administered the VOMS, followed by the mBESS. One of our objectives was to demonstrate that VOMS and mBESS testing could be conducted in military-specific environments. The VOMS and mBESS were administered in a variety of environments, including clinical examination rooms, on parachute drop zones, in the field during training exercises, in the maritime dive facility, on the sidelines during mixed martial arts and combatives competitions, and at unit recreational events. The total test time for each participant was approximately 15 to 20 minutes.

Data Analyses

Descriptive statistics comparing risk factors between groups were calculated for continuous (mean and SD) and categorical (frequency [%]) variables. We used independent-samples *t* tests and χ^2 analyses to compare participants with normal VOMS scores to those with ≥1 VOMS items above the clinical cutoffs (ie, ≥2 on any VOMS symptom provocation item, >5-cm NPC distance).[5] For the mBESS, false-positive rates were determined based on a total mBESS score of >4 using 95% CIs per Covassin et al.[14] Backward stepwise multivariable logistic regression (LR) models were calculated to predict false-positive scores on the VOMS and mBESS, with demographics (eg, age in year, sex [male or female], military service in years, deployment months, and MOS [operator or nonoperator]) and medical history (mTBI, migraines, and motion sickness) factors as predictors. A *P* value of <.1 was used for initial model entry. Post hoc diagnostics of each model were conducted to assess for multicollinearity and variance inflation. All statistical analyses were performed using SPSS (version 25; IBM Corp), with statistical significance set at $P < .05$.

RESULTS

Comparison of Demographics and Medical History

Complete data were available for 399/416 (96%) participants. A comparison of demographic and medical history risk factors among participants with normal VOMS and mBESS scores with those who had false-positive results are presented in Tables 1 and 2. We found no differences between VOMS groups by age, sex, MOS, years of military service, or deployment time. False-positive VOMS symptom scores were associated with a history of migraine, motion sickness, or mTBI (*P* values < .05; Table 1). A false-positive for NPC distance was associated with mTBI history but no other factors (Table 1). We observed no between-groups mBESS differences for age, sex, MOS, years of military service, deployment time, mTBI history, or migraine history. False-positive total mBESS scores were associated with a motion sickness history (Table 2).

False-Positive Rates for the VOMS and mBESS

Overall, 21.9% (91/415) of the sample had ≥1 false-positive on the VOMS. The false-positive rates for individual VOMS items ranged from 10.6% (smooth pursuits) to 17.5% (NPC distance) (Table 3). The mBESS total score false-positive rate was higher at 36.5% (151/415; Table 3).

Multivariable LR Models for False-Positives on the VOMS and mBESS

Results of the multivariable LR for VOMS false-positives are summarized in Table 4. The overall LR model was statistically significant at $P < .001$ with an R^2 of 0.08 (LR $\chi^2_5 = 34.48$). The LR model supported 3 significant predictors: age (adjusted odds ratio [aOR] = 1.07), migraine history (aOR = 2.49), and motion sickness history (aOR = 2.46), with 2 nonsignificant predictors contributing to the model variance (mTBI history: aOR = 1.57, $P = .09$ and operator MOS: aOR = 0.56, $P = .07$). Results of the

Table 3. Summary of Normal and False-Positive (ie, Above Clinical Cutoff) Vestibular-Ocular Motor Screening and Modified Balance Error Scoring System Scores in Healthy US Army Special Operations Command Personnel

Test	Mean ± SD	% (No.)	
		Normal	False-Positive
Vestibular-Ocular Motor Screening item			
Smooth pursuits	0.44 ± 1.43	89.4 (372)	10.6 (44)
Horizontal saccades	0.50 ± 1.54	88.2 (367)	11.8 (49)
Vertical saccades	0.53 ± 1.65	88.0 (366)	12.0 (50)
Near point of convergence	0.52 ± 1.66	88.7 (369)	11.3 (47)
Near point of convergence distance, cm	3.00 ± 3.28	82.5 (329)	17.5 (70)
Horizontal vestibular-ocular reflex	0.63 ± 1.84	85.7 (355)	14.3 (59)
Vertical vestibular-ocular reflex	0.64 ± 1.99	86.7 (358)	13.3 (55)
Visual motion sensitivity	0.74 ± 2.06	84.8 (352)	15.2 (63)
Modified Balance Error Scoring System total score	3.83 ± 2.54	62.9 (263)	36.5 (151)

multivariable LR for false-positives on mBESS total score are summarized in Table 5. The overall LR was statistically significant at $P = .003$ with an R^2 of 0.02 (LR $\chi^2_1 = 9.16$) and supported only motion sickness history (aOR = 2.34, $P = .002$) as a significant predictor.

DISCUSSION

We examined false-positive rates and associated risk factors for false-positives on the VOMS and mBESS among healthy military personnel. False-positive rates for VOMS items in this population ranged from 11% to 18%, with an overall false-positive rate on ≥1 VOMS items of 22%. The false-positive rate for the mBESS total score was nearly 37%. Previous researchers[7] reported that false-positive rates on the VOMS in healthy collegiate student-athletes ranged from 6% for vertical VOR to 11% for NPC distance. Our range of false-positives was slightly higher but paralleled these trends, with NPC (18%) at the high end and smooth pursuits and other oculomotor items (11%) at the low end. One might think that our higher false-positive rates for VOMS reflect residual effects from exposure to repeated blasts and undiagnosed mTBIs in the operational environment common to USASOC (ie, Special Forces) operators. However, an analysis of MOS and false-positives on ≥1 VOMS items was not significant ($P = .07$). Our false-positive rate for the mBESS (37%) was much higher than the only other demonstrated false-positive rate (approximately 6% in high school athletes) for the mBESS using the 95% CI.[14] The threshold for a false-positive on the mBESS from the earlier investigation was much higher at 9 total errors than our 4 total errors. Given these results, we suggest that VOMS individual items have acceptable rates of false-positives in healthy military personnel. More than one-third of healthy military personnel had a false-positive finding on the mBESS, which suggests that the clinical utility of this tool to help identify mTBI in this population may be limited.

We also highlight the role of demographic and medical history factors in false-positive results among healthy US military personnel. Overall, more than two-thirds (64%) of false-positives on the VOMS items were associated with ≥1 medical history factors (eg, previous mTBI, migraine, or motion sickness or all 3). A history of motion sickness was associated with higher odds of false-positives on both the VOMS (aOR = 2.46) and mBESS (aOR = 2.34). In addition, older age (aOR = 1.07) and a history of migraines (aOR = 2.49) were also associated with higher odds of VOMS false-positives. Female sex (OR = 2.99) and a history of migraine (OR = 1.47) or motion sickness (7.73) were all associated with false-positives on the VOMS in healthy collegiate student-athletes.[7] Risk factors such as migraines and motion sickness have been associated with decreased vestibular system functioning in healthy people and appeared to confound the results of vestibular-ocular motor testing after concussion.[7,17,18] These findings highlight the need to consider demographic and medical history factors when administering the VOMS and interpreting the outcomes. A history of mTBI was the only factor associated with false-positives for average NPC distance, and a history of motion sickness was the only factor associated with false-positives on the mBESS. These results highlight the importance of considering key demographic and medical history factors when interpreting VOMS, average NPC distance, and mBESS scores after mTBI.

We provide useful information to assist military medical professionals, including frontline medics, in administering and interpreting the components of the MACE-2 for personnel with a suspected mTBI. Understanding the role of risk factors in false-positives on the VOMS and mBESS components of the MACE-2 can inform clinical decision making when a suspected mTBI lacks diagnostic clarity.

Table 4. Backward Multivariate Logistic Regression Analysis of ≥1 False-Positive Results on Any Vestibular-Ocular Motor Screening Item in Healthy US Army Special Operations Command Personnel[a]

Risk Factor	*P* Value	Adjusted Odds Ratio	Standard Error	z Statistic	95% CI
Age, y	.007[b]	1.07	0.03	2.69	1.02, 1.12
≥1 Mild traumatic brain injury	.090	1.57	0.42	1.69	0.93, 2.65
History of migraine	.007[b]	2.49	0.84	2.72	1.29, 4.81
History of motion sickness	.004[b]	2.46	0.76	2.92	1.34, 4.50
Military occupation specialty (operator)	.072	0.56	0.18	–1.80	0.30, 1.05

[a] $R^2 = 0.08$; $P < .001$; logistic regression $\chi^2 = 34.48$; n = 414).
$P < .05$.

Table 5. Backward Multivariate Logistic Regression Analysis of False-Positive Results on the Modified Balance Error Scoring System Total Score (>4 Errors) in Healthy US Army Special Operations Command Personnel[a]

Risk Factor	*P* Value	Adjusted Odds Ratio	Standard Error	z Statistic	95% CI
History of motion sickness	.002[b]	2.34	0.66	3.02	1.35, 4.05

[a] $R^2 = 0.02$; $P = .003$; logistic regression $\chi^2 = 9.16$; n = 413.
[b] $P < .05$.

For example, when an operator has a possible concussion from a mechanism that is not obvious, with no observable concussion signs, and is reporting low-level symptoms with only mild VOMS provocation, a medical history of migraine or motion sickness or both may explain VOMS-related symptoms. Clinicians should be cautious when a VOMS-mBESS false-positive might have occurred and consider this possibility in the context of a comprehensive, multidomain assessment. The potential risks of dismissing a real mTBI based on only a possible VOMS or mBESS false-positive could have long-term implications (eg, sustaining a subsequent mTBI before the first has healed).

A history of motion sickness was associated with both vestibular-ocular motor and vestibulo-spinal findings. This factor should be considered when interpreting clinical findings in postinjury evaluations of these domains. Older age but not years in service or total months of deployment was also associated with higher odds of false-positives on VOMS symptom items and warrants attention when administering the MACE-2 to older personnel. Exposure to blasts and head impacts over time from both deployment and training activities could influence the vestibular and ocular motor systems.[19] This supposition was partially supported by the higher false-positive rates for some VOMS items, such as NPC distance and VMS, than previously noted in research involving athletes.[7] However, data on the number of blast exposures or head impacts or both over time were not available to us. Data on MOS, which can serve as a proxy for these exposures, were collected, but no association between operator and non-operator status was supported by the analysis. This finding may have been related to the lack of nuance in examining specific MOSs (eg, MOS 13B, canon and artillery crewmember) in the current sample. Given that total months of deployment and years in service were not associated with VOMS or mBESS false-positives, these factors, along with blast exposure and head impacts, should be the focus of future studies.

With the VOMS and mBESS findings, especially in regard to factors associated with false-positives, an initiative to conduct baseline evaluations may be valuable when assessing the health of both injured and uninjured military personnel. Performing the VOMS in healthy personnel before and after training and deployment would be useful for establishing baseline and postexposure data. These data could help identify patients with possible mTBIs and evaluate the effects of training and deployment involving blast, artillery, combatives, breaching, or jumps. The baseline and postexposure administrations would allow for evaluations both before and after vestibular and ocular motor symptoms and impairment, as well as provide an opportunity for discussion and awareness of mTBI and its effects among military personnel. Some personnel in our investigation revealed concerns about being removed from their team or duties if they were to test positive or report any mTBI-related symptoms, even in this baseline study. Although we did not evaluate the reasons for not reporting mTBI symptoms, a stigma appears to persist surrounding seeking medical care after a suspected mTBI. Our protocol was intended to leverage awareness of mTBI and reduce the stigma of seeking care for mTBI in this population.

Strengths and Limitations

We involved a large sample of healthy USASOC personnel who represented different ages, MOSs, years of military service, and total lengths of deployment. Despite these strengths, we acknowledge several limitations. The VOMS testing was purposefully conducted across different operational settings to demonstrate that it could be easily administered in a variety of environments. Our outcomes may have been influenced by the testing environments. Insufficient consistency among testing environments prevented us from aggregating environments such that we could statistically examine this potentially confounding effect. Participants were limited to USASOC personnel and included few females. As such, the results may not be generalizable to the overall US military population or female personnel, as USASOC personnel are held to a higher operational and physical standard than the general military. Finally, the inclusion and exclusion criteria were designed to ensure that only healthy military personnel were tested. Therefore, we assumed that participants accurately reported information about these criteria; however, a myriad of factors may influence the accuracy of mTBI history and symptom self-reporting in this and other study populations.

CONCLUSIONS

The findings supported low false-positive rates across VOMS items in USASOC personnel, with false-positives being associated with age and a history of mTBI, migraine, or motion sickness. False-positives for the mBESS total score were higher (36.5%) but were associated only with a history of motion sickness. Military medical personnel should evaluate and consider these factors associated with false-positive rates when administering the VOMS and mBESS and interpreting the results in this at-risk population. Future researchers should examine the comparative utility of these tools in conjunction with other components of the MACE-2 for identifying and tracking recovery after mTBI in military personnel.

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