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Normative Data for the NeuroCom Sensory Organization Test in US Military Special Operations Forces

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Context: Postural stability is the ability to control the center of mass in relation to a person's base of support and can be affected by both musculoskeletal injury and traumatic brain injury. The NeuroCom Sensory Organization Test (SOT) can be used to objectively quantify impairments to postural stability. The ability of postural stability to predict injury and be used as an acute injury-evaluation tool makes it essential to the screening and rehabilitation process. To our knowledge, no published normative data for the SOT from a healthy, highly active population are available for use as a reference for clinical decision making.

Objective: To present a normative database of SOT scores from a US Military Special Operations population that can be used for future comparison.

Design: Cross-sectional study.

Setting: Human performance research laboratory.

Patients or Other Participants: A total of 542 active military operators from Naval Special Warfare Combatant-Craft Crewmen (n = 149), Naval Special Warfare Command, Sea, Air, and Land (n = 101), US Army Special Operations Command (n = 171), and Air Force Special Operations Command (n = 121).

Main Outcome Measure(s): Participants performed each of the 6 SOT conditions 3 times. Scores for each condition, total equilibrium composite score, and ratio scores for the somatosensory, visual, and vestibular systems were recorded.

Results: Differences were present across all groups for SOT conditions 1 ($P < .001$), 2 ($P = .001$), 4 ($P > .001$), 5 ($P > .001$), and 6 ($P = .001$) and total equilibrium composite ($P = .000$), visual ($P > .001$), vestibular ($P = .002$), and preference ($P > .001$) NeuroCom scores.

Conclusions: Statistical differences were evident in the distribution of postural stability across US Special Operations Forces personnel. This normative database for postural stability, as assessed by the NeuroCom SOT, can provide context when clinicians assess a Special Operations Forces population or any other groups that maintain a high level of conditioning and training.

Key Words: normative data, NeuroCom, Sensory Organization Test

Key Points

- The assessment of postural stability is an essential component for the prevention of lower extremity injuries, which is a significant health concern in military populations.
- The Sensory Organization Test is used to objectively quantify and differentiate among sensory, motor, and central adaptive impairments to postural stability.
- Establishing normative values for the Sensory Organization Test in Special Operations Forces will assist researchers and clinicians when using the test in similar populations.

Lower extremity musculoskeletal injury and low back pain in the military population are associated with high medical costs and a significant amount of lost or modified time from duty, lessening military readiness. In 2004, lower extremity overuse injuries resulted in 3 million days of limited duty for the Department of Defense.[1] In addition, blast injuries have been defined as the signature injury of conflicts in Iraq and Afghanistan. This is concerning in the military population because of the associated short-term disability, potential long-term cognitive effects, chronic pain, and possible permanent neurologic injury.[2]

With the large number of musculoskeletal injuries in the military, new injury-prevention approaches are needed to reduce their effects. Many of these injuries occur during dynamic activity,[3] when a person's center of mass is

Table 1. Descriptive Data by Special Forces Group

Group	n	Mean ± SD			
		Age, y	Height, cm	Mass, kg	Body Fat, %
Naval Special Warfare Combatant-Craft Crewmen	149	26.47 ± 4.91	178.71 ± 6.63	84.15 ± 9.02	19.14 ± 5.29
Naval Special Warfare Command, Sea, Air, and Land	101	29.87 ± 6.38	177.11 ± 6.40	85.87 ± 11.60	16.47 ± 6.76
US Army Special Operations Command	171	33.46 ± 6.40	179.71 ± 5.77	86.50 ± 11.00	18.50 ± 6.65
Air Force Special Operations Command	121	27.63 ± 4.90	177.29 ± 5.92	83.75 ± 8.36	16.63 ± 5.37
Total	542	29.57 ± 6.37	178.41 ± 6.25	85.12 ± 10.10	17.88 ± 6.14

constantly changing to maintain balance. *Postural stability* is the ability to control the center of mass in relation to a person's base of support and can be affected by both musculoskeletal injury and traumatic brain injury.[4] By studying deviations in the center of mass, movement away from an upright body position, and subsequent corrective torques, the amount of postural sway can be established.[5] Increased postural sway is a predictor of future ankle and knee injuries in athletic populations.[6,7] Decreased postural stability is 1 risk factor associated with new and recurrent lower extremity injuries in an active population.[8] Diminished postural stability has also been shown after ankle,[9] knee,[10] and low back[11] injuries.

The ability of postural stability to both predict injury and be used as an acute injury-evaluation tool makes its inclusion essential in a screening or rehabilitation process. Postural stability can be measured by a large variety of tests, including instrumented and noninstrumented measures. Force plates are commonly used to quantitatively measure postural sway as an assessment of injury status or to track the effects of rehabilitation and training.[12,13] Postural-stability testing has traditionally been used to assess musculoskeletal deficits; however, it has recently become a method of assessment in the concussed population as well.[14] The NeuroCom Balance Manager Systems (NeuroCom International, Inc, Clackamas, OR) use computerized dynamic posturography, an assessment technique that objectively quantifies and differentiates among sensory, motor, and central adaptive impairments to postural stability. During the NeuroCom Sensory Organization Test (SOT) protocol, the participant's sensory information is altered by calibrated "sway referencing" of the support surface or visual surroundings (or both), which tilt to directly follow the patient's anterior-posterior body sway.[15]

Objective measurements of postural stability are important in an active population, especially in the US Military. The US Special Operations Command encompasses the Special Operations Forces (SOFs) of all military branches. The SOF Operators have large physical demands placed on them during year-round military training and tactical missions across a wide variety of environmental conditions. The Air Force Special Operations Command's core mission is to provide rapid global deployment to enable airpower success through tactical air and ground integration. The US Army Special Operations Command Naval Special Warfare Command, Sea, Air, and Land (SEAL) personnel are trained to operate in all environments for which they are named (sea, air, and land) but are uniquely trained for maritime endeavors. The US Navy's Special Warfare Combatant-Craft Crewmen, under the Naval Special Warfare Command, are primarily responsible for the insertion and extraction of SEAL platoons as well as other SOFs. These continuous, rigorous physical demands under extreme conditions often lead to musculoskeletal injuries.[16] The high level of physical fitness among elite service members influences their ability to maintain postural control, possibly allowing them to achieve above-average SOT scores compared with a general population. Subtle changes in training methods across SOFs groups may result in differences in postural-stability scores.[17] This demonstrates the need for NeuroCom scores specific to this population. To aid in preventing or mitigating the potential for lower extremity musculoskeletal injury, a comprehensive screening process should be implemented. A key component of this comprehensive screening, based on its ability to predict future injury, is balance.

Normative SOT scores for children,[18] the elderly,[19] and patients with vestibular disorders[20] have been published, but no such data have been published for a military-specific or highly active population, to our knowledge. The primary purpose of our study was to present a normative database for SOT scores from a US Military Special Operations population so that the scores can be compared with those of any groups who maintain a high level of conditioning and training. The secondary purpose was to investigate whether performance differed among SOFs.

METHODS

Participants

Participants were 542 active-duty military operators from Naval Special Warfare Combatant-Craft Crewmen (n = 149), Naval Special Warfare Command, Sea, Air, and Land (n = 101), US Army Special Operations Command (n = 171), and Air Force Special Operations Command (n = 121; Table 1). Volunteers were excluded from the study if they were not cleared for full active duty. Descriptive statistics, including age, height, mass, and body fat, of each Special Operations group are provided in Table 1. All operators tested were male due to the nature of this specific population. All participants were informed of the testing procedures and signed a written consent form approved by the university's institutional review board, which also approved the study. All testing was conducted at the human performance research laboratory of each respective SOFs component.

Instrumentation

A NeuroCom Balance Master equipped with the Data Acquisition Toolkit (software version 2.0) was used to assess postural stability. The Balance Master is equipped with two 9- × 18-in (23- × 46-cm) force plates connected

Table 2. Sensory Organization Testing[a]

Test Condition	Eyes	Surroundings	Platform	Sensory System Used
1	Open	Fixed	Fixed	Somatosensory
2	Closed	NA	Fixed	Somatosensory
3	Open	Sway referenced	Fixed	Somatosensory
4	Open	Fixed	Sway referenced	Vision
5	Closed	NA	Sway referenced	Vestibular
6	Open	Sway referenced	Sway referenced	Vestibular

Abbreviation: NA, not applicable.

[a] Adapted from *Balance Manager Systems Clinical Interpretation Guide Computerized Dynamic Posturography*, NeuroCom International, Inc.[21]

by a pin joint. Both the support surface and the visual surroundings rotate in the anterior-posterior plane referenced to the participant's sway and sway velocity.

Procedures

Participants were asked to remove all footwear and then were positioned with standardized foot placement relative to their height. They were instructed to stand with their arms relaxed at their sides, look straight forward, and stand as still as possible. The participants performed all 6 of the SOT's conditions and repeated each trial 3 times.[21] Each trial was 20 seconds in duration. Each person completed the testing in the standardized order as shown in Table 2.

By controlling the use of sensory information through sway referencing and eyes-open or -closed conditions, the SOT protocol systematically eliminates useful visual and support-surface information and creates sensory-conflict situations.[22] Participants need to overcome these sensory conflicts to maintain good postural stability.

An equilibrium score was generated based on how well the participant remained in his theoretical limits of stability (established as a total of 12.5° in the anterior-posterior direction). Less postural sway in the anterior-posterior direction results in a higher equilibrium score, indicating greater postural stability. If the participant fell or received a negative value (sway more than the theoretical limit of 12.5°), he received an equilibrium score of 0 for that condition's trial.[15] An overall composite equilibrium score was computed using the weighted average of all scores, with the more difficult conditions (3–6) receiving higher weights. A higher composite score indicates better postural control.[14] Using the average equilibrium score for each condition, ratio pairs were generated to see how well the participants used the specific sensory systems (Table 3). The *sensory analysis ratio scores* for the somatosensory, visual, and vestibular systems express how well a participant is able to use those specific cues for balance. The *preference ratio* defines how well a participant can ignore inaccurate visual clues in a situation of visual conflict.[22]

Table 3. Sensory Analysis Ratios[a]

Ratio	Condition Comparison
Somatosensory	2 to 1
Visual	4 to 1
Vestibular	5 to 1
Preference	(3 + 6) to (2 + 5)

[a] Adapted from *Balance Manager Systems Clinical Interpretation Guide Computerized Dynamic Posturography*, NeuroCom International, Inc.[21]

Data Analysis

All statistical analyses were performed using SPSS (version 21.0; IBM Corp, Armonk, NY). Descriptive statistics (mean, median, and standard deviation) for all groups combined and each SOFs group were calculated. Normality was tested using a Shapiro-Wilk test ($\alpha = .05$), and the data were not normally distributed. A Kruskal-Wallis test was used to compare SOT scores among groups ($\alpha = .05$). Post hoc Mann-Whitney *U* testing was conducted for variables that were statistically significant. A Bonferroni correction was applied to post hoc tests.

RESULTS

All operators successfully performed all 3 trials of each condition, with none receiving an equilibrium score of 0. Means and standard deviations for each SOT condition and ratio score are presented by individual SOFs groups and all groups combined in Table 4. A Kruskal-Wallis comparison showed differences across all groups for SOT conditions 1 ($P < .001$), 2 ($P = .001$), 4 ($P < .001$), 5 ($P < .001$), and 6 ($P = .001$) and overall composite equilibrium ($P < .001$), visual ($P < .001$), vestibular ($P = .002$), and preference ($P < .001$) scores (Table 4). The medians and interquartile ranges for all SOFs combined, which were not used within the analysis, are also given in Table 4. Post hoc analysis using the Mann-Whitney test with a Bonferroni correction showed differences in median scores among groups (Table 5).

DISCUSSION

This study provides a normative database of postural stability assessed by the SOT for US SOFs. Poor postural stability is a risk factor for ankle, knee, and low back injury.[6,7] To our knowledge, we are the first to present SOT scores across military SOFs. Data from our research will assist clinicians working with military or highly active populations by providing comparison values from a similar population. These normative values can also be used to evaluate patients with traumatic brain injuries to see if they are returning to normal postural stability as assessed by the SOT. Furthermore, these data may be beneficial in screening for an elevated risk of lower extremity injury once the relationship between SOT score and injury is established.

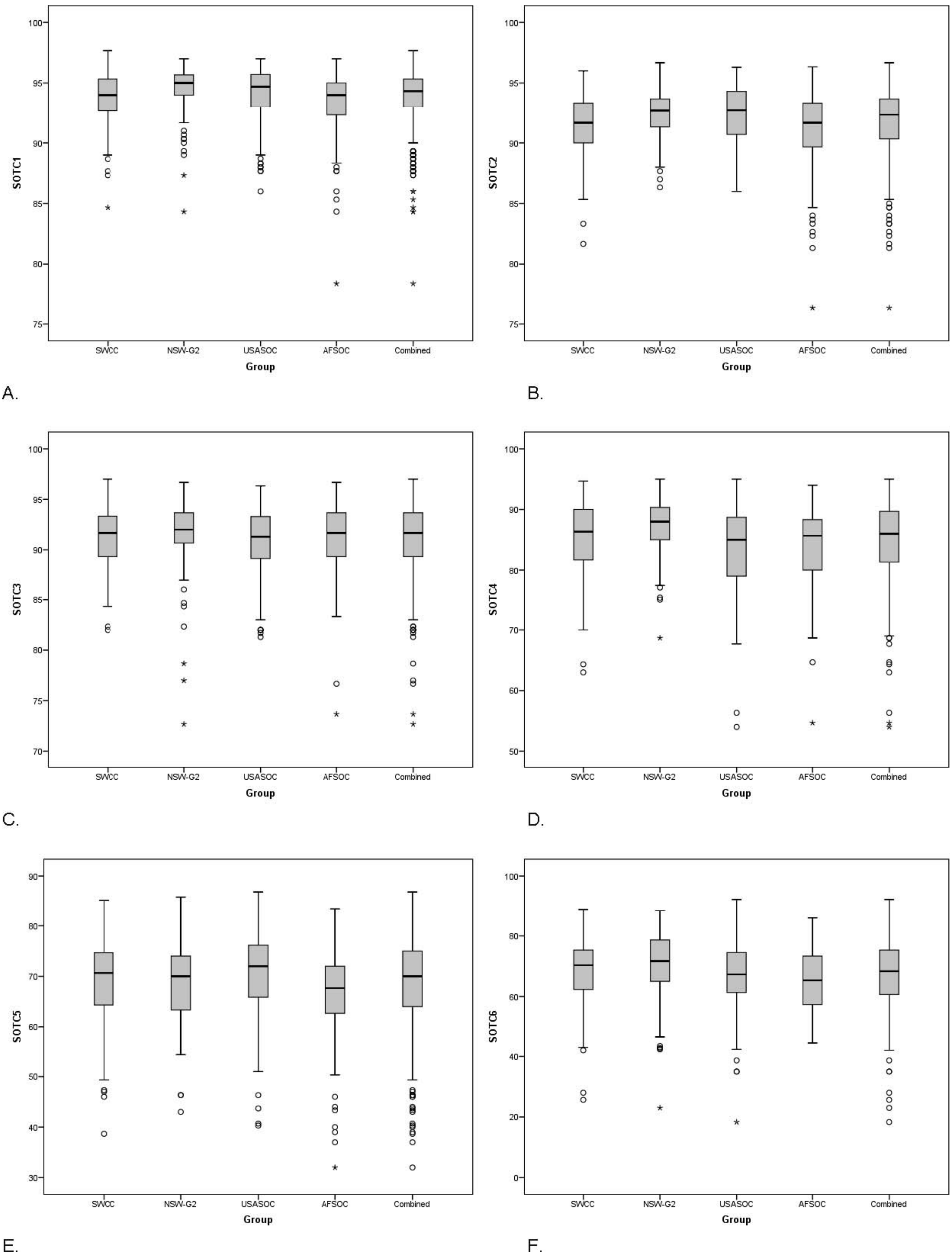
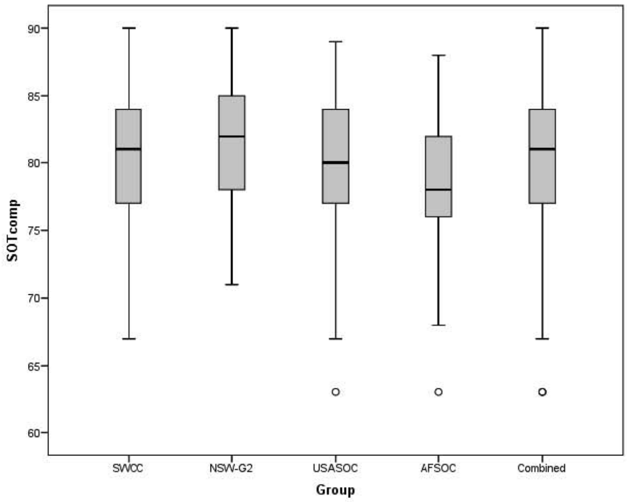


Figure. Measures by Special Forces Group. The box plots illustrate the distribution of each Sensory Organization Test condition (SOTC) and sensory ratio score by Special Operations Forces group. Abbreviations: AFSOC, Air Force Special Operations Command; NSW-G2, Naval Special Warfare Command, Sea, Air, and Land; SWCC, Naval Special Warfare Combatant-Craft Crewmen; USASOC, US Army Special Operations Command.



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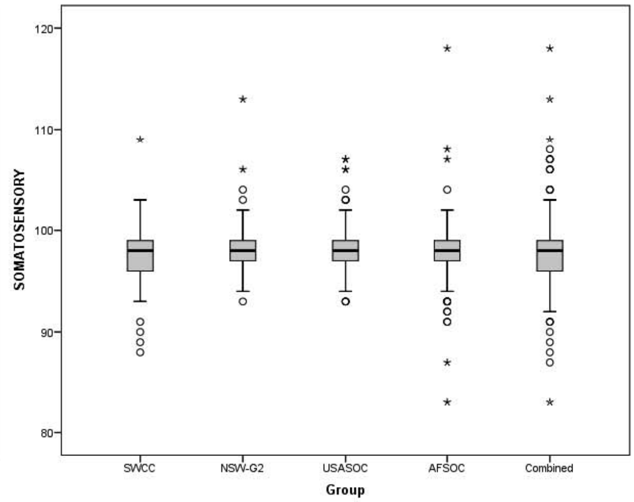

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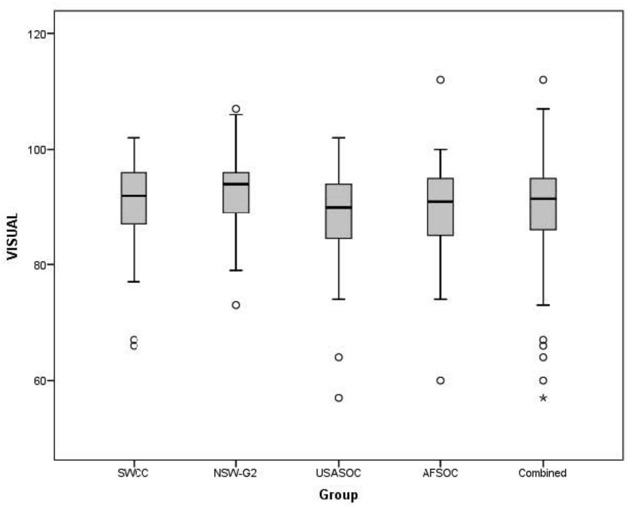

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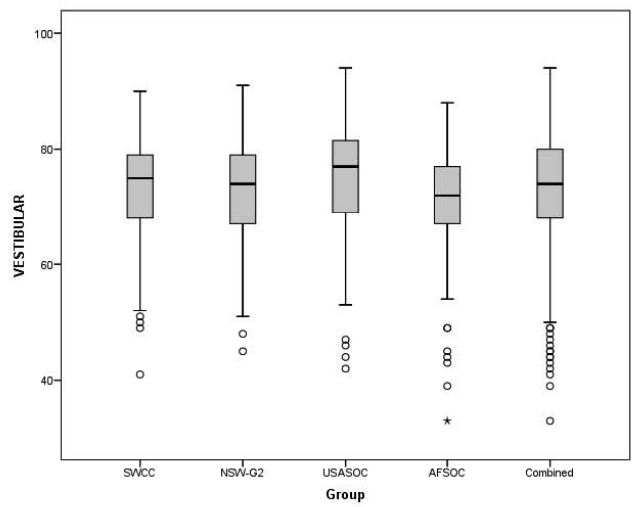

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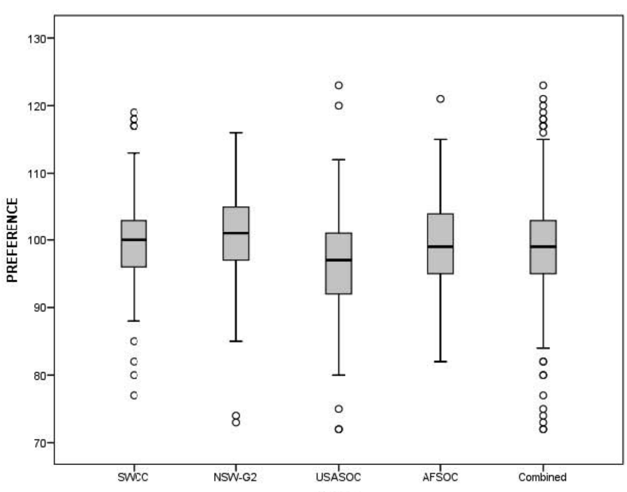

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Figure. Continued from previous page.

Table 4. Sensory Organization Test Scores, Mean ± SD, Median (Interquartile Range)

Group	Condition[a] 1[a]	2[a]	3	4[a]	5[a]	6[a]	Composite[a]	Somatosensory	Visual[a]	Vestibular[a]	Preference[a]
Naval Special Warfare	93 ± 2	91 ± 2	91 ± 2	85 ± 5	68 ± 8	68 ± 10	80 ± 4	97 ± 2	91 ± 6	73 ± 9	99 ± 6
Combatant-Craft Crewmen	94 (92–95)	91 (90–93)	91 (89–93)	86 (81–90)	70 (64–74)	70 (61–75)	81 (77–84)	98 (96–99)	92 (87–96)	75 (68–79)	100 (96–103)
Naval Special Warfare	94 ± 2	92 ± 2	91 ± 3	87 ± 4	68 ± 8	70 ± 11	81 ± 4	98 ± 2	92 ± 5	72 ± 8	100 ± 7
Command, Sea, Air, and Land	95 (94–95)	92 (91–93)	92 (90–93)	88 (84–90)	70 (63–74)	71 (64–78)	82 (78–85)	98 (96–99)	94 (89–96)	74 (67–79)	101 (97–105)
US Army Special Operations	94 ± 2	92 ± 2	90 ± 3	83 ± 6	70 ± 8	66 ± 10	80 ± 4	98 ± 2	88 ± 7	74 ± 9	96 ± 6
Command	94 (93–95)	92 (90–94)	91 (89–93)	85 (79–88)	72 (65–76)	67 (61–74)	80 (77–84)	98 (97–99)	90 (84–94)	77 (69–82)	97 (92–105)
Air Force Special Operations	93 ± 2	91 ± 3	91 ± 3	83 ± 6	66 ± 9	65 ± 10	78 ± 4	97 ± 3	89 ± 7	70 ± 9	99 ± 7
Command	94 (92–95)	91 (89–93)	91 (89–93)	85 (79–88)	67 (62–72)	65 (57–73)	78 (76–82)	98 (97–99)	91 (85–95)	72 (67–77)	99 (95–109)
Combined	93 ± 2	91 ± 2	91 ± 3	84 ± 6	68 ± 8	67 ± 10	80 ± 5	97 ± 2	90 ± 6	73 ± 9	98 ± 7
	94 (93–95)	92 (90–93)	91 (89–93)	86 (81–89)	70 (64–75)	68 (60–75)	81 (77–84)	98 (96–99)	91 (86–95)	74 (68–80)	99 (95–103)

[a] Kruskal-Wallis test for comparison among 4 groups was significant at the .05 level.

Postural control requires the coordination of multiple sensorimotor systems to maintain the center of mass within the limits of stability.[23] The SOT uses a combination of fixed and sway-referenced motion conditions to test balance. The resulting scores provide information about the assimilation of the visual, proprioceptive, and vestibular components of balance.[15] Previous investigators looked at the SOT as a way to assess and track rehabilitation progress in participants with vestibular deficits[20,24] and central nervous system disorders[25] and in an aging population.[26,27] The use of the SOT in a healthy population is a relatively new concept. Scores in our military population were similar to those in a healthy young adult population (age = 20–22 years)[28] and a collegiate athlete population.[29] Average data for our SOFs were lower across conditions than for healthy volunteers, aged 21 to 30 years, as noted by Borah et al.[30] These data were cited in the NeuroCom *Clinical Interpretation Guide*, Appendix A.[21] Age groups were divided into 10-year intervals, and only 10 participants were included in each age group. However, our averages were higher than the data currently used for normative values and listed in the *Clinical Interpretation Guide*, Table A1,[21] indicating a need for a database of normative values from military-specific or highly active populations.

Our results show that the multidimensional components of postural stability may be affected by the tactical demands of the individual military branches. The statistical difference in the distribution of SOT scores among groups emphasizes the need to have a normative database specifically for individual SOFs (Figure). Statistical differences were seen between operators for SOT conditions 1, 2, 4, 5, and 6 as well as the composite, visual, vestibular, and preference scores. Similarities in distribution among groups for SOT condition 3 and somatosensory scores may reflect the disadvantaged visual system (sway-referenced surround) of the condition, thereby forcing the participant to rely on the somatosensory system. Differences among groups may be a result of their specific tactical training, mission environment, and equipment. Balance and proprioception improvements have been shown to occur in an athletic population as a result of participating in their sport.[31] In our experience with SOFs, different tactical demands among groups may lead to subtle postural-stability differences.

Having a normative database to compare with an individual's current postural-stability score can help determine who may be at risk of future injury. Along with adaptations to tactical training, balance-training programs can be used to decrease the risk of injury. Balance training has commonly been used to improve performance and prevent injury in an active population.[32] Training focuses on heightening the sensorimotor system for more efficient automatic muscular responses to maintain postural control.

One limitation of this study is that participants may have had previous injuries (including concussion, which affects balance when tested in isolation) but were cleared for full military active duty. A limitation of the Balance Master itself is its theoretical limit of stability of 12.5°. If a participant has postural sway greater than 12.5°, the equilibrium score would be negative. The sample we assessed for this study consisted of more than 100 SOF operators each from the Navy, Army, and Air Force. This sample provided a good characterization of postural

Table 5. Mann-Whitney Test Values for Pairwise Comparisons of Special Forces Groups

Pairs		Condition[a] 1	2	4	5	6	Composite	Somatosensory	Visual	Vestibular
SWCC	NSW-G2	0.002[a]	0.002[a]	0.033	0.561	0.222	0.150	0.132	0.359	0.238
SWCC	USASOC	0.062	0.002[a]	0.020	0.061	0.081	0.484	0.006[a]	0.081	<0.001[a]
SWCC	AFSOC	0.136	0.834	0.046	0.007	0.004[a]	0.005[a]	0.187	0.025	0.868
NSW-G2	USASOC	0.131	0.784	<0.001[a]	0.033	0.007[a]	0.045	<0.001[a]	0.021	<0.001[a]
NSW-G2	AFSOC	<0.001[a]	0.012	<0.001[a]	0.096	0.000[a]	<0.001[a]	0.007[a]	0.401	0.231
USASOC	AFSOC	0.001[a]	0.009	0.905	0.000[a]	0.138	0.020	0.241	<0.001[a]	0.001[a]

Abbreviations: AFSOC, Air Force Special Operations Command; NSW-G2, Naval Special Warfare Command, Sea, Air, and Land; SWCC, Naval Special Warfare Combatant-Craft Crewmen; USASOC, US Army Special Operations Command.

[a] Significant difference at Bonferroni-corrected critical *P* value of .008.

stability for a specifically defined population. Authors of future prospective studies should look at performance on the SOT as a predictor of future injury. They should also consider the effect of balance training on the postural stability of Special Forces personnel.

In conclusion, we found statistical differences in postural stability across US SOFs. This normative database for postural stability, assessed by the SOT, can supply context when assessing SOFs or other highly active populations.

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