Postural Stability of Special Warfare Combatant-Craft Crewmen With Tactical Gear

Paul M. Morgan, MS; Valerie J. Williams, DPT; Timothy C. Sell, PhD

ABSTRACT

Background: The US Naval Special Warfare's Special Warfare Combatant-Craft Crewmen (SWCC) operate on small, high-speed boats while wearing tactical gear (TG). The TG increases mission safety and success but may affect postural stability, potentially increasing risk for musculoskeletal injury. Therefore, the purpose of this study was to examine the effects of TG on postural stability during the Sensory Organization Test (SOT). **Methods:** Eight SWCC performed the SOT on NeuroCom's Balance Manager with TG and with no tactical gear (NTG). The status of gear was performed in randomized order. The SOT consisted of six different conditions that challenge sensory systems responsible for postural stability. Each condition was performed for three trials, resulting in a total of 18 trials. **Results:** Overall performance, each individual condition, and sensory system analysis (somatosensory, visual, vestibular, preference) were scored. Data were not normally distributed therefore Wilcoxon signed-rank tests were used to compare each variable (p = .05). No significant differences were found between NTG and TG tests. No statistically significant differences were detected under the two TG conditions. This may be due to low statistical power, or potentially insensitivity of the assessment. Also, the amount and distribution of weight worn during the TG conditions, and the SWCC's unstable occupational platform, may have contributed to the findings. The data from this sample will be used in future research to better understand how TG affects SWCC. **Conclusion:** The data show that the addition of TG used in our study did not affect postural stability of SWCC during the SOT. Although no statistically significant differences were observed, there are clinical reasons for continued study of the effect of increased load on postural stability, using more challenging conditions, greater surface perturbations, dynamic tasks, and heavier loads.

Keywords: postural stability; tactical gear; sensory organization test; Navy; SWCC

Introduction

Tactical gear (TG) worn by US military members has significantly increased in weight since the late 19th century to loads that may exceed the Soldier's body weight.[1] The amount of gear worn for protection and tactical operation has significantly contributed to improving military operations. The added weight, however, appears to increase pain and the risk for musculoskeletal injury, which is a significant problem in the US military: more than 700,000 such injuries were reported as of 2006.[1-4] The cause of musculoskeletal injuries may be due to multiple factors, including overuse, performing military duties in body armor, or even leisure activities and exercise.[3,5-7]

One risk factor for injury is decreased postural stability or, simply stated, one's balance.[8,9] Postural stability can be affected by the increased amount of weight worn by military Servicemembers by moving the center of mass superiorly and anteriorly, altering sensory input, hindering response time, increasing task difficulty by influencing mobility, and increasing the risk for musculoskeletal injury.[1,3,4,10-15] Schiffman et al.[16] observed decreased postural stability in military personal performing static tasks with weights of 6kg, 16kg, and 40kg. The addition of load carriage has been shown to increase postural sway during static upright stance, suggesting that the external load negatively affects the ability of the individual to maintain postural stability while decreasing mobility for occupational tasks.[11,12,16] Further, Sell et al.[17] performed a standardized jumping task to simulate military activities and observed that TG negatively affects dynamic postural stability. It was concluded that the observed decrement in dynamic postural stability when wearing TG may lead to increased risk for musculoskeletal injury.[17]

Although there have been numerous studies of postural stability and military load carriage, the effect of body armor on postural stability of Special Operations Forces (SOF) Special Warfare Combatant-Craft Crewmen (SWCC) is unknown. The postural stability of this specific group is particularly important because of the specialized environment and conditions in which they work. SWCC perform special missions on small, high-speed water craft on ocean and small-river water systems for the insertion and extraction of SOF in areas where larger water craft cannot effectively maneuver. When performing military tactical training or completing a mission, the SWCC must wear body armor and TG on the craft and maintain proper postural stability to safely and efficiently complete the mission. The effect of load carriage on SWCC is unknown.

The purpose of this study was to determine if body armor and TG affects postural stability in SWCC. It was hypothesized that the addition of body armor and TG would negatively affect postural stability and, therefore, may increase risk for lower extremity musculoskeletal injury. The results of this study will provide insight into the effects of load carriage on postural stability and potential need for physical training techniques to mitigate the negative effects that load carriage may have on postural stability.

Methods

Participants

Eight SWCC who cleared for full active duty participated in this study (mean ± standard deviation [SD]: age, 27.1 ± 6.9 years; height, 180.8cm ± 6.5cm weight, 90.7kg ± 5.7kg). All subjects were informed of the testing procedures and provided written informed consent prior to testing. This study was approved by the University of Pittsburgh institutional review board. The crewmen were tested with TG and without tactical gear (NTG) in a randomized order. Each crewman wore standard operational gear, weighing a mean (±SD) of 21.7kg ± 1.1kg, for TG tests that included body armor, blue weapons (also known as plastic simulation weapons), plastic ammunition magazines, and helmet and night optic devices.

Instrumentation

The NeuroCom Balance Manager Smart EquiTest (Natus Medical Inc., http://balanceandmobility.com) was used to determine postural stability. The apparatus is equipped with two force sensors and a dynamic visual surround that are used to provide challenging support and visual conditions. NeuroCom's standardized protocol for the Sensory Organization Test (SOT) was used to assess postural stability and consists of six conditions, each having three consecutive trials. The six conditions (C1–C6) of the SOT are (1) eyes open with stationary support, (2) eyes closed with stationary support, (3) eyes open with dynamic surround, (4) eyes open with dynamic support, (5) eyes closed with dynamic support, and (6) eyes open with dynamic surround and support. The SOT provides an overall composite score (SOTcomp) and four sensory analysis scores: somatosensory (SOM), visual (VIS), vestibular (VEST), and preference (PREF). These scores indicate the ability of the subject to use information from the indicated sensory system to maintain postural stability (i.e., SOM, VIS, VEST) when the sensory input is accurate. The PREF score indicates the subject's ability to maintain postural stability using inaccurate visual information.

Procedures

Height and weight for each crewman with and without TG were measured. The crewmen performed the SOT in accordance with NeuroCom's standard operating procedure based on each subject's height. The crewmen were instructed to maintain proper foot position and to maintain their normal standing balance, with arms to their side and while looking straight ahead. Crewmen performed the NTG unshod, according to standard procedures, but wore tactical footwear during the TG protocol. Researchers observed foot position throughout the protocol to ensure compliance with the manufacturer's operation procedure. The harness provided by NeuroCom was used only during the TG tests to catch in the event of a fall, but researchers ensured it did not impede mobility. No falls were observed during testing.

TG and NTG tests were completed in a randomized order. Balance was scored for overall performance, each of the six conditions, and sensory system analysis scores for SOM, VIS, VEST, and PREF. Normality was assessed using the Shapiro-Wilk test with statistical significance set at $p < .05$. Data were not normally distributed; therefore, Wilcoxon signed-rank tests were used to compare each subject's performance on each postural stability variable between TG and NTG conditions with significance set a priori at $p < .05$.

Results

The means, standard deviations, median values, and interquartile ranges for each SOT variable (SOTcomp, SOM, VIS, VEST, PREF, and C1–C6) are included in Table 1. The Wilcoxon signed-rank test revealed no differences in SOT performance for any of the postural stability variables with and without wearing TG.

Discussion

The effect that load carriage has on SWCC postural stability, specifically SOT performance, is unknown. Therefore, the purpose of this study was to determine if body armor and TG affect postural stability in SWCC. We hypothesized that the addition of body armor and TG would decrease postural stability, but our hypothesis was not supported. In our study, SWCC were able to maintain the same postural stability performance with the SOT when wearing 21.7kg ± 1.1kg on the upper body as without the TG. The statistical analysis revealed no significant differences between conditions for the SOTcomp, SOM, VIS, VEST, or PREF scores.

Table 1 *Special Warfare Combatant-Craft Crewmen Operator SOT Performance With and Without Tactical Gear*

	No Tactical Gear				Tactical Gear				
SOT Variable	**Mean**	**SD**	**Median**	**IQR**	**Mean**	**SD**	**Median**	**IQR**	***p* value**
SOTcomp	76.75	5.82	77.50	9.00	76.75	4.65	74.50	9.00	.93
SOM	94.38	4.57	96.00	8.00	93.75	5.06	95.50	8.00	.78
VIS	87.63	5.15	88.00	11.00	90.88	2.17	91.00	4.00	.07
VEST	70.50	9.35	70.50	10.00	71.63	6.50	71.00	11.00	.53
PREF	97.50	4.11	96.50	7.00	97.25	4.65	97.00	6.00	1.00
C1	92.50	4.16	93.84	5.84	93.12	1.59	93.33	2.75	1.00
C2	87.92	5.49	90.34	10.33	86.50	4.83	87.67	8.25	.16
C3	89.46	5.75	90.84	10.50	87.21	3.42	87.83	5.59	.12
C4	81.63	6.41	81.00	12.17	84.25	3.31	84.17	5.25	.16
C5	66.04	9.65	66.50	9.00	65.67	7.38	62.50	11.41	.78
C6	62.04	9.42	66.67	17.84	60.67	9.36	59.00	11.58	.89

C1, eyes open with stationary support; C2, eyes closed with stationary support; C3, eyes open with dynamic surround; C4, eyes open with dynamic support; C5, eyes closed with dynamic support; C6, eyes open with dynamic surround and support; IQR, interquartile range; PREF, preference analysis score; SD, standard deviation; SOM, somatosensory analysis score; SOT, Sensory Organization Test; SOTcomp, overall composite score; VEST, vestibular analysis score; VIS, visual analysis score.

When compared with other studies, the SOTcomp scores of our subjects during the NTG tests were slightly lower. Several other studies reported SOTcomp scores ranging from 80 to 82.33 for healthy young adults.[18-20] These subjects likely had better scores because they were younger. One study[18] reported SOTcomp scores for 31–40-year-old subjects to be 78.6, which was still higher than those in our study. The differences observed in our group compared with other studies demonstrate a need for larger studies, specifically in the SOF population, so that crewmen may be compared with similar subjects. It is interesting to note that the NTG score of our group (n = 8) is lower than the average of SWCC participating in a larger prospective study being conducted by our research group. Unpublished data from our laboratory, from a study of 149 subjects, suggest the average SOTcomp score of SWCC is 80.39. It is possible that the small group used for these analyses did not perform as well as the average for SWCC or other healthy adult groups. It is unknown if crewmen with a higher NTG score would perform differently with the addition of TG.

It is also possible that we did not find an effect of TG on postural stability, because of the amount and placement of the weight used. Park et al.[4] suggest that even distributions of weight could lead to improved postural stability by decreasing body sway. They observed no significant differences in the center of pressure excursions between military training college students wearing evenly weighted tactical vests with ceramic plates and those wearing compression sport shorts. However, they observed that uneven distributions of weight significantly increased anteroposterior center of pressure excursions (COP).[4] This increase in COP excursion during static stance has been observed with posterior loading of TG weighing 16kg and that weighing 40kg.[16] The distribution of weight from this study was not measured; however, SWCC carry body armor with front and rear protective ballistic plates, anteriorly placed ammunition magazines, and a posteriorly placed rifle to create a more evenly weighted distribution, which would be similar to one of the conditions used by Park et al.,[4] where weight was placed both anteriorly and posteriorly on the tactical vest. The weight distribution of the helmet in this study was also not calculated, but the forward-facing night optic devices along with a counter weight placed posteriorly on the helmet may create an evenly distributed weight on the head. It is possible that the total weight, or the distribution, included in this study may not be enough of a challenge to observe change in postural stability.

The lack of change between NTG and TG SOM, VEST, VIS, and PREF scores could also be due to increased exposure of SWCC to the varying pitch, yaw, and roll of the water craft, leading to greater postural stability that begins during qualification training and remains a consistent exposure throughout their career. It is understood that repeated exposure to on-water environments causes an increase in vestibular cues while providing lower instance of motion sickness, which is caused by a conflict of sensory systems.[21-24] Tal et al.[24] studied motion sickness in naval crew members and observed habituation of motion sickness and increased SOT scores after 6 and 12 months of water-craft exposures. Similarly, somatosensory function related to postural stability may be trained by consistently wearing gear. The helmet worn can weigh up to 2.5kg and places significant strain on the cervical muscles, which play a primary role in maintaining spatial orientation because of the high density of muscle spindles and Golgi tendon organs that are responsible for proprioceptive input for postural control.[25-28] These spindles make up what Kavounoudias and Gilhodes[29] described as the "proprioceptive chain," allowing input to travel from the one location of the body to another to aid postural control and body orientation. The high volume of tactical training undertaken by the SWCC while wearing helmets may increase the rate at which the muscle spindle fires, allowing for faster reaction to sudden perturbations and improved postural stability. The amount of time wearing helmets, often more than 4 hours per training day, may have also increased muscular strength and endurance of the cervical muscles, allowing SWCC to maintain postural stability without experiencing cervical fatigue. This is interesting because previous literature has shown decreased postural stability with exercise-induced fatigue of the cervical extensors.[25,26,30]

It is also possible the degree of difficulty of the SOT may not have been great enough to elicit significant change between wearing TG and not wearing TG. Other studies have shown significant changes in gait when load was added to military Soldiers compared with normal gait pattern with changes in knee range of motion, forward head posture, and pelvis rotation during dynamic movement.[10,31] Dynamic postural stability is another aspect of balance that allows researchers to assess postural stability in a valid, reliable, and more functional manner.[32] One such test involves jumping off of two feet, landing on one foot, and subsequent postural stabilization upon a force plate.[32] This task may be more challenging to SWCC and may reveal greater difference in SOT when the SWCC remain stationary even in challenging sensory conditions. A more challenging dynamic task may be more appropriate because these types of movements are necessary in some aspects of military training, such as land-based tactical skills and leaping on and off of the craft. Further, other literature has observed decreased dynamic postural stability during a single-leg landing jump task in US Army Soldiers while wearing TG.[17] Decrement in dynamic postural stability may increase the risk for lower limb musculoskeletal injury, potentially to a greater degree than static postural stability tasks.

Although no statistical differences were found, it is important to consider the potential clinical significance of differences observed. Rounding to the nearest whole number, for ease of clinical interpretation, reveals a difference score of 3 for the SOTcomp, with the crewmen performing worse while wearing TG. It is the opinion of the authors that clinical significance may be observed with a change of 3 or more in the SOTcomp score. A change of 3 in the score may be a clinically significant difference when investigating differences in SWCC because, in highly trained crewmen, a small difference may indicate a clinically meaningful difference in performance.[33,34] The difference in median score for the SOM, VEST, and PREF scores is 0. This lack of change indicates that the crewmen experienced no difference in their ability to use somatosensory, vestibular, or inaccurate visual information when wearing TG versus NTG. The difference in the VIS median score was 3, with the crewmen performing better with their TG on. Therefore, SWCC may use visual input to a greater degree under a challenging balance condition with the addition of TG.

Limitations

This study is not without limitations. Only a small sample of SWCC was recruited to participate. Also, the crewmen wore tactical footwear during the TG tests, which may influence the results of the SOT. NeuroCom's Balance Manager Smart Equitest system does allow footwear to be worn in cases in which the individual is unable to remove their footwear (i.e., elderly populations), but states that testing should be done under similar conditions unless differences between shod and unshod protocols was the primary measure. Also, the SOT uses an equilibrium score to assess postural stability combining the somatosensory, visual, and vestibular systems into one score. The equilibrium score is based upon an equation that has a set theoretical limit of stability of 12.5° often seen the normal population.[35] Chaudhry et al.[35] believe this may also be a limitation because individuals outside of the normal population may have a higher limit of stability and, therefore, a theoretical inaccurate result from the SOT may be observed because of this set limit.

Conclusion

SWCC performed very similarly on the SOT with and without wearing TG. This demonstrates that the sensory systems of the SWCC responded similarly with and without TG to maintain postural stability. There may be a slight clinically significant difference indicating that SWCC use their visual system more while wearing TG even though no statistically significant differences were found in the SOTcomp score. The researchers believe the primary reasoning behind the similar performance is due to frequent exposure to an unstable occupational platform. This exposure would drive the development, and likely improvement, of postural stability under the conditions tested in the current study. Therefore, the risk of incurring lower extremity musculoskeletal injury due to postural instability may be diminished, but this risk should not be completely dismissed, because safety is still imperative to completing any task while carrying a load. Based upon the findings of this study and the nature of the SWCC operational task, further investigation of postural stability during more challenging testing conditions, such as greater surface perturbations, dynamic tasks, and heavier loads, may elicit changes in postural stability not observed here.

Funding

This work was supported by the US Navy's Office of Naval Research under Award N00014-10-1-0912/ N00014-11-1-0929.

Disclaimer

Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the US Navy.

Disclosures

The authors declare no conflicts of interest.

References

1. **Knapik J, Reynolds K, Harman E.** Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med.* 2004;169:45–56.
2. **Hauret KG, Jones BH, Bullock SH, et al.** Musculoskeletal injuries: description of an under-recognized injury problem among military personnel. *Am J Prev Med.* 2010;38:S61–S70.
3. **Konitzer LN, Fargo MV, Brininger TL, et al.** Association between back, neck, and upper extremity musculoskeletal pain and individual body armor. *J Hand Ther.* 21:143–149.
4. **Park H, Branson D, Kim S, et al.** Effect of armor and carrying load on body balance and leg muscle function. *Gait Posture.* 2014;39:430–435.
5. **Bullock SH, Jones BH, Gilchrist J, et al.** Prevention of physical training-related injuries: recommendations for the military and other active populations based on expedited systemic reviews. *Am J Prev Med.* 2010;38:S156–S181.
6. **Jones BH, Perrotta DM, Canham-Chervak ML, et al.** Injuries in the military: a review and commentary focused on prevention. *Am J Prev Med.* 2000;2000:3S.
7. **Kaufman KR, Brodine K, Shaffer R.** Military training-related Injuries surveillance, research, and prevention. *Am J Prev Med.* 2000;18:54–63.
8. **Meguine TA, Greene JJ, Best T, et al.** Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med.* 2010;10:239–244.
9. **Sell TC.** An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adult. *Phys Ther Sport.* 2011;12:80–86.
10. **Attwells R, Birrell S, Hooper R, et al.** Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics.* 2006;49:1527–1537.
11. **Dempsey PC, Handcock PJ, Rehrer NJ.** Impact of police body amour and equipment on mobility. *Appl Ergon.* 2013;44: 957–961.
12. **Kincl LD, Bhatacharya A, Succop PA, et al.** Postural sway measurements: a potential safety monitoring techniques for works wearing personal protective equipment. *Appl Occup Environ Hyg.* 2002;17:256–266.
13. **Mahoney C, Hirsch E, Hasselquist L, et al.** The effects of movement and physical exertion on soldier vigilance. *Aviat Space Environ Med.* 2007;78:B51–B57.
14. **May B, Tomporowski P, Ferrara M.** Effects of backpack load on balance and decisional processes. *Mil Med.* 2009;174: 1308–1312.
15. **Treloar A, Billing D.** Effect of load carriage on performance of an explosive, anaerobic military task. *Mil Med.* 2011;176: 1027–1031.
16. **Schiffman JM, Bensel CK, Hasselquist L, et al.** Effects of carried weight on random motion and traditional measures of postural sway. *Appl Ergon.* 2006;37:607–614.
17. **Sell T, Pederson J, Abt J, et al.** The addition of body armor diminishes dynamic postural stability in military soldiers. *Mil Med.* 2013;178:76–81.
18. **Borah D, Wadhwa S, Singh U, et al.** Age related changes in postural stability. *Indian J Physiol Pharmacol.* 2007;51:395–404.
19. **Guskiewicz KM, Riemann BL, Perrin DH, et al.** Alternative approaches to the assessment of mild head injury in athletes. *Med Sci Sports Exerc.* 1997;29(Suppl):S213–221.
20. **Peterson ML, Christou E, Rosengren KS.** Children achieve adult-like sensory integration during stance at 12-years-old. *Gait Posture.* 2006;23:455–463.
21. **Diels C, Howarth PA.** Frequency characteristics of visually induced motion sickness. *Hum Factors.* 2013;55:595–604.
22. **Golding JF.** Motion sickness susceptibility. *Auton Neurosci.* 2006;129:67–76.
23. **Shahal B, Nachum Z, Spitzer O, et al.** Computerized dynamic posturography and seasickness susceptibility. *Laryngscope.* 1999;109:1996–2000.
24. **Tal D, Ronen B, Nachum Z, et al.** Postural dynamics and habituation to seasickness. *Neurosci Lett.* 2010;479:134–137.
25. **Duclos C, Roll R, Kavounoudias A, et al.** Long-lasting body leanings following neck muscle isometric cotnractions. *Exp Brain Res.* 2004;158:58–66.
26. **Gosselin G, Rassoulian H, Brown I.** Effects of neck extensor muscle fatigue on balance. *Clin Biomechanics.* 2004;19: 473–479.
27. **Kim G, Oh D.** Neck proprioceptive training for balance fucntion with chroni porststroke hemiparesis: a case series. *J Phys Ther Sci.* 2014;26:1657–1659.
28. **Vuillerme N, Pinsault N, Vaillant J.** Postural control during quiet staning following cervical muscular fatigue: effect of changes in sensory inputs. *Neurosci Lett.* 2005;378:135–139.
29. **Kavounoudias A, Gilhodes J.** From balance regulation to body orientation: two goals for muscle proprioceptive information processing? *Exp Brain Res.* 1999;124:80–88.
30. **Schieppati M, Nardone A, Schmid M.** Neck muscle fatigue affects postural control in man. *Neurosci.* 2003;121:277–285.
31. **Birrell SA, Haslam RA.** The effect of military load carriage on 3-D lower limb kinematics and spatiotemporal parameters. *Ergonomics.* 2009;52:1298–1304.
32. **Wikstrom EA, Tillman MD, Smith AN, et al.** A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Jl Athl Train.* 2005;40:305–309
33. **Batterham A, Hopkins WG.** Making meaningful inferences about magnitudes. *Sport Sci.* 2005;9:6–13.
34. **Rhea MR.** Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res.*2004;18:918–920.
35. **Chaudhry H, Findley T, Quigley KS, et al.** Measures of postural stability. *J Rehabil Res Dev.* 2004;41:713–720.

Mr Morgan is affiliated with the Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, Pennsylvania. E-mail: paulminwookimmorgan@gmail.com.

Dr Williams is affiliated with the Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, Pennsylvania.

Dr Sell is affiliated with the Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, Pennsylvania. E-mail: TCS15@pitt.edu.