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RESEARCH ARTICLE

The Influence of the Beiring Sorenson Hold and the Barbell Back Squat on Running Cadence in Military Ruck Marching: A Cross-Sectional Observational Study

Shane Robinson[1,*], Gregory Palevo[2], and Nathan Boys[3]

ABSTRACT

Ruck marching is a key performance indicator for tactical preparation; however, marching under load causes changes in biomechanics, which can increase injury risk. Although this risk of injury from changes is known, current methods commonly used for assessing physical fitness have not adequately identified how to minimize these changes. In this observational study, 14 ROTC cadets underwent a series of physical muscular fitness tests prior to performing a six-mile ruck march. These included an evaluation of postural endurance via the Biering Sorenson hold, lower body strength via the back squat, and upper body strength via bench press. After the tests were performed, ruck march performance was evaluated by total time to completion and running dynamics. Multiple regression analysis was performed to determine if bench press maximum, back squat maximum, or Sorenson hold were predictors of the performance of the ruck March.

Average cadence shared a positive significant relationship with the Sorenson hold ($r = 0.76$, $p = 0.02$) and a negative significant relationship with the back squat ($r = -0.76$, $p = 0.02$). Additionally, the Sorenson hold did not share any significant relationships with total ruck time ($r = -0.3$, $p = 0.29$) or ground contact time ($r = -0.41$, $p = 0.31$). The back squat did not share significant relationships with ground contact time ($r = -0.37$, $p = 0.37$) or average smoothness ($r = -0.38$, $p = 0.31$). This study highlights the potential relationship that the Sorenson hold and back squat can have on running cadence, which has shown significant changes in previous research evaluating the changes in running performance and characteristics from weight ruck marching. Further investigation of the relationship of these assessments on the performance of ruck marching should be performed with larger numbers of cadets in the future.

Keywords: Injury prevention, ruck march, Sorenson hold, tactical performance.

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[1] *MS, Northeast Georgia Medical Center, GME-Research, USA.*
[2] *PhD, Department of Kinesiology, Albany State University, USA.*
[3] *DO, Northeast Georgia Medical Center, GME-Family Medicine, USA.*

Corresponding Author:
e-mail: shanerobinson656@gmail.com

1. Introduction

Military ruck march training is a benchmark for military training and tactical preparation (Earl-Boehm *et al.*, 2020). This form of training requires participants to perform long-distance carries with weighted rucksacks and equipment ranging from 16 to 32 kilograms, which includes military training equipment such as helmets, rifles, and canteens. Most cadets and military soldiers have healthy, considerably "fit" cardiorespiratory fitness that prepares them for long-distance runs; however, rucksack positioning negatively impacts running economy and body position, hindering performance and leading to a high risk of injuries (Schuh-Renner *et al.*, 2017).

The additional load carried during the ruck march causes a shift in body position, which tends to cause a change in dynamic stability and running gait (Lyons *et al.*, 2021). Evaluation of local dynamic lower extremity stability is a common analysis to detect inadequate gait, and fall risk is a common practice for health within the elderly and can be used to determine risk factors in activities that are involved with highly reported injuries (Bizovska *et al*., 2018). This measure was used to assess the overall change between a non-weighted ruck march and a weighted ruck march on gait mechanics, trunk body position, and running economy. Military cadets experienced with ruck marching completed 200-second duration ruck marches on a treadmill without any load, a plastic frame ruck, and a metal frame ruck. While the frame material did not cause any differences, the marches with the loaded ruck caused significant changes in overall body position, dynamic stability, and running economy (Moon *et al*., 2021). Additionally, these changes have also been transferred to running characteristics in field marches between an unweighted and weighted six-mile ruck march with noticeable decreases in average cadence, average smoothness, and rating of perceived exertion (Walsh *et al*., 2021).

The change in body position, dynamic stability, and running economy during loaded ruck marching can lead to chronic injuries if not properly assessed (Earl-Boehm *et al*., 2020). These altercations include added stress to the ankles, knees, and hips that continued to increase with additional weight from the ruck (Almonroeder *et al*., 2021). The additional stress of lower extremity loading can lead to bone stress injuries (Earl-Boehm *et al*., 2020). These acute effects from repeated ruck marches can result in chronic injuries over time. Over six months, 50% of total military training-related injuries among 831 soldiers were caused by either load ruck marching or distance running (Schuh-Renner *et al*., 2017). The areas most commonly injured are the lower extremities and the lower back due to the additional impact and change in body position required to move the additional weight over various distances (Schuh-Renner *et al*., 2017).

While the risks of chronic injuries involved with ruck marching have been established, loaded carries are essential to military training as this is a common requirement in military duties (Kyröläinen *et al*., 2018). Therefore, physical preparation of muscular strength and endurance should be a priority to potentially decrease the incidence of injury and further improve the physical performance of military soldiers. The barbell back squat is a common metric of maximal lower body strength and has transferability to sprint performance (Seitz *et al*., 2014). The barbell's position in the back squat requires greater activation of the trunk extensors compared to other squatting variations and can be more comparable to the position experienced in ruck marching (Krzyszkowski & Kipp, 2020).

The Beiring Sorenson Hold is an exercise test designed to measure the endurance of back extensors and overall postural endurance (Coorevits *et al*., 2008). This test focuses on the endurance and strength of trunk extensors related to chronic low back pain (Latimer *et al*., 1999). The Sorenson hold has been used to assess athletes in various sports where lower back pain is common (Durall *et al*., 2009), and this assessment needs limited equipment and is not taxing on its participants (Ozcan Kahraman *et al*., 2016). Postural endurance is very important in the aspect of maintaining balance, vertical oscillation, and lower back health with carrying heavy loads over long distances in ruck marching, but there is currently no research on the relationship between postural endurance and ruck marching performance or the prevalence of lower back pain in tactical athletes that participate in ruck marching.

Additionally, the barbell back squat is one of the most common lower body strength assessments used on general and athletic populations (Krzyszkowski & Kipp, 2020). While lower body strength in the form of a barbell back squat has not been thoroughly investigated in its potential relationship with ruck march performance, this is one of the few exercises that carries its load posteriorly, similarly to a weighted ruck. The back squat has shown transferability to sprinting mechanics and force production for competitive sprinters (Möck *et al*., 2021). Increases in maximal strength allow for additional force reserves in the biomechanical demands required for distance running (Seitz *et al*., 2014), and these demands are further increased with the additional weight from the required ruck marches, which makes strength in the barbell back squat a potential predictor for ruck march performance.

It is evident that weighted ruck marching causes changes to running characteristics and ground reaction forces (Almonroeder *et al*., 2021; Hannan & King, n.d.; Moon *et al*., 2021; Walsh *et al*., 2021), but there is minimal research on which exercises can help minimize these effects for improved performance and decrease risk in injuries from its demands that alters running characteristics (Walsh *et al*., 2021). Therefore, the purpose of this cross-sectional observational study was to determine if muscular performance measures in the barbell back squat, the bench press, and the Sorenson hold have any relationship with running characteristics and running performance during a loaded ruck march in college military cadets. We hypothesize that these assessments possess a relationship with running characteristics and ruck march performance and can help guide not only future practice of assessments but also training structures to help better prepare military personnel for the demands of weighted ruck marching.

2. Method

2.1. Subjects

A total of 14 third-year military college cadets in the University of North Georgia ROTC program participated in this cross-sectional observational study. All participants were primarily male (10 male, 4 female), similar in age (M = 20.2, SD = 0.56), and had similar experience in ruck march training before participating in the study. All cadets were considered physically fit according to cardiorespiratory fitness guidelines, with a peak oxygen consumption recorded from a submaximal Bruce protocol (M = 43.78, SD = 7.27). The study was conducted on ethical grounds for the participants, and all aspects of the study were approved by the institutional review board at the University of North Georgia. The ethical clearance was received from the University of North Georgia's institutional review board and filed under IRB number 2020-105. All participants signed an informed consent form before participating.

2.2. Physiological Assessment

Before beginning the six-mile ruck march, all participants completed an assessment of postural endurance with the Sorenson hold during a series of physical fitness tests (body composition, submaximal VO_2, lower body strength test, upper body strength test). The university's human performance laboratory, which provided the area for assessing the cadets, did not have a glute and ham developer to perform the Sorenson hold. In this case, all participants were instructed to lay in a pronated position on a flat bench with their hips hanging off the pad, cross their arms over their chest and shoulders, tuck their chin into their chest, and a member of the research team helped anchor down their legs so the cadets could utilize their glutes and hamstrings to perform the hold. All participants were provided with the ability to practice the hold before executing the test. The research team explained to each cadet the test's goal was to hold a neutral extended position for as long as physically possible and only had one attempt. The maximal Sorenson holds was recorded in seconds.

2.3. Six-Mile Ruck March

All subject cadets performed the six-mile ruck march together with the other ROTC members participating in the ruck march program. Each cadet was provided a Garmin Forerunner watch and a Garmin running dynamics pod to measure the running kinematics, cardiovascular, and metabolic responses to the ruck march. All cadets were ordered to complete the six-mile ruck as quickly as possible and were not told to carry the equipment in any particular position. This ruck march was performed on a route through the university campus, which all participants had run and were accustomed to before completing this study.

2.4. Outcomes

The outcome of the focus of this study was the relationship between the performance of the pre-ruck Sorenson hold, strength in the bench press and back squat, and the performance markers of the ruck march. These performance measures included total time, average cadence, average smoothness, vertical oscillation, and ground contact time. These variables consisted of the measures recorded in the physiological assessment session (body fat percentage, peak VO_2, bench press strength, back squat strength, and the Sorenson hold).

2.5. Statistical Analysis

To determine if any of the pre-assessment muscular performance measures had a relationship with ruck marching performance, a Pearson correlation analysis was used. The strength of the relationship was defined as strong (0.8 to 1.0 or −0.8 to −1), moderate (0.4 to 0.8 or −0.4 to −0.8), and weak (0.1 to 0.4 or −0.1 to −0.4). Furthermore, to determine if any running performance or strength markers predicted 6-mile ruck performance, a multivariate linear regression model was performed. We used an alpha level of 0.05 for all statistical tests.

3. Results

A total of 14 college cadets participated in this cross-sectional observational study. The majority of the participants were male (n = 10) and were, on average, 20.2 ± 0.56 years of age with an average height of 69.04 ± 4.23 inches and an average body weight of 167.44 ± 31.12 pounds. Body composition was assessed with air displacement plethysmography with the CosMed Bod Pod, and the participants had an average recorded body fat of 16.64 ± 9.79%. All participants were considered physically "fit" with an average relative peak oxygen consumption of 43.78 ± 7.27 mL.kg.min that was achieved in a

TABLE I: Physiological Assessment Measures

Variable	Mean	Standard deviation
Age (yr)	20.2	0.56
Height (in)	69.04	4.23
Weight (lb)	167.44	31.12
Body fat (%)	16.64	9.79
Bench press (lb)	162.36	58.32
Back squat (lb)	221.64	62.53
Sorenson hold (sec)	64	24.12
Peak VO_2 (ml.kg.min)	43.78	7.27

TABLE II: Running Performance and Characteristics in Six-Mile Ruck March

Variable	Mean	Standard deviation
Six mile ruch time (sec)	4636	494.62
Ground contact time	310.13	47.3
Vertical oscillation	3.24	1.13
Smoothness	101.11	21.17
Average cadence	136.11	6.29
Maximum cadence	200	15.13

submaximal Bruce protocol that was completed when participants achieved 85% of the age-predicted max heart rate (Table I).

All participants completed the 6-mile ruck march in an average of 4636 seconds, which is equivalent to 77.27 minutes and is under the required time set by the US military. The running characteristics of the participants were measured by an average ground contact time of 310.13 ± 47.3 ms, vertical oscillation of 3.24 ± 1.13 cm, average smoothness 101.11 ± 21.17, average cadence 136.11 ± 6.29 steps/minute, and maximum cadence 200 ± 15.13 steps/minute (Table II).

A multiple regression analysis was conducted to determine if 1RM bench press, 1RM back squat, or Sorenson hold were predictors of performance in the six-mile ruck march measured in time to completion. The regression results conclude the model did not significantly predict the six-mile ruck march performance [$R^2 = 0.145$, $R^2_{adj.} = -0.111$, F (3, 10) = 153920.68, $p = 0.65$]. The model accounted for 14.5% of the variance in the time to complete the six-mile ruck march (Table III). While this model is not significant, 1RM back squat was shown to potentially have a positive effect on the model, while 1RM bench press and time in the Sorenson hold have a negative effect (Table IV).

A correlational analysis was used to determine any relationship between muscular performance in the bench press, back squat, and the Sorenson hold with any of the running characteristics evaluated during the six-mile ruck march (Table V). The Sorenson hold only had a significant strong positive correlation with the average cadence during the ruck march ($r = 0.76$, $p = 0.02$), but did not have any other significant correlations. The Sorenson hold held a moderate negative but not significant correlation with ground contact time ($r = 0.41$, $p = 0.31$) and a weak negative but not significant correlation with ruck time ($r = -0.3$, $p = 0.29$). Like the Sorenson hold, the back squat possessed a strong positive and significant correlation with the average cadence during the ruck march ($r = 0.76$, p

TABLE III: Multiple Regression Model Summary

R	R square	Adjusted R square	Std. error of the estimate	Changed statistics		
				R square change	F change	df
0.381	0.145	−0.111	521.41	0.145	0.566	3

TABLE IV: Multiple Regression Model for Predictors of Ruck March Performance

Variables	Unstandardized coefficients		Standardized coefficients		
	B	SE	Beta	t	p
Constant	5369.585	745.975	–	7.198	<0.001
1RM bench press	−2.224	4.313	0.262	0.516	0.617
1RM back squat	0.315	4.088	0.04	0.077	0.94
Sorenson hold	−6.91	6.184	−0.337	−1.117	0.29

TABLE V: Correlational Analysis of Muscular Strength and Endurance with Running Characteristics

	Sorenson hold	Back squat	Bench press
Ruck time	$r = -0.3$ ($p = 0.29$)	$r = -0.09$ ($p = 0.74$)	$r = -0.17$ ($p = 0.55$)
Ground contact time	$r = -0.41$ ($p = 0.31$)	$r = -0.37$ ($p = 0.37$)	$r = 0.25$ ($p = 0.55$)
Oscillation	$r = -0.01$ ($p = 0.98$)	$r = 0.37$ ($p = 0.42$)	$r = 0.36$ ($p = 0.42$)
Average smoothness	$r = 0.09$ ($p = 0.82$)	$r = -0.38$ ($p = 0.31$)	$r = -0.07$ ($p = 0.85$)
Average cadence	**$r = 0.76$ ($p = 0.02$)**	**$r = -0.76$ ($p = 0.02$)**	$r = -0.46$ ($p = 0.21$)
Total steps	$r = 0.29$ ($p = 0.32$)	$r = -0.09$ ($p = 0.77$)	$r = -0.06$ ($p = 0.84$)

$= 0.02$) but did not share any significant relationships with ground contact time ($r = -0.37$, $p = 0.37$) or average smoothness ($r = -0.38$, $p = 0.31$).

4. Discussion

This study aimed to determine if the back squat, bench press, or Sorenson hold can help predict performance in a six-mile ruck march. While none of these three exercises significantly predicted the time to complete the six-mile ruck march, we believe the meaningfulness of the moderate correlations between the exercise movements and running characteristics could share a new perspective of strength and endurance assessments that could be furthered by future research to determine better the best pre-assessment and training recommendations for performance and injury resilience in weighted ruck marching for military personnel.

The Sorenson hold possessed a moderate negative correlation with ground contact time. This relation can be due to the postural endurance required in the Sorenson hold to help the cadets maintain a better trunk position and optimal oscillation supporting the additional weight from the ruck over long distances, resulting in decreased ground contact time (Adams *et al*., 2018; Harris *et al*., 2010). Maximal strength in the back squat also showed a negative correlation, but this was slightly weaker than the relationship between ground contact time and the Sorenson hold. These findings can be explained by previous findings of strength training and its benefits from improved running economy with athletes at given speeds over middle and long distances (Blagrove *et al*., 2018; Trowell *et al*., 2022). Running economy results from improved or better-maintained running characteristics and correlates with grounding contact time in distance running (Di Michele & Merni, 2014; Mooses *et al*., 2021). Compared to other strength assessments, the back squat can provide a more tactical-specific assessment, with the posterior loading replicating the additional load provided by the rucksack requiring more strength compared to most endurance running events.

The back squat and the Sorenson hold significantly correlated with the average cadence. The back squat had a strong negative correlation, and the Sorenson hold held a strong positive correlation. Previously, college military cadets who completed an unweighted and weighted ruck march on the same course experienced a mean decrease of 22 steps per minute in the weighted ruck march (Walsh *et al*., 2021). While these are observations, the Sorenson hold may allow the cadets to hold a more secure and stable position with the weighted ruck, possessing adequate postural endurance (Latimer *et al*., 1999). While the strength in the back squat might help support the ruck's weight, endurance can be a more critical factor, with ruck march distances varying from 4–12 miles. Lastly, the back squat had a noticeable positive correlation with average smoothness. Although it may not be significant, having a larger sample size in future research can help better determine if assessments have the potential to be significant predictors of ruck march performance.

A primary limitation of this study was that we only had 10 successful recordings of running characteristics with the dynamics pod. 4 participants experienced the pod coming off during the ruck march or having connection issues where it did not interpret any of the metrics accurately. While we only had ten participants, we believe this study should help shed light on future research investigating an optimal physical assessment to help improve performance and decrease the high rate of injuries experienced in ruck marching.

Ruck marching is a physically demanding task for military personnel. While this task is unavoidable, further research should be conducted to determine the most appropriate assessments and exercises to utilize in order to prepare participants better and minimize injuries. While the Sorenson hold and back squat only correlated significantly with average cadence, these findings and insights should be elaborated upon with larger study samples to determine their potential for physical preparation in military personnel.

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Data Availability

The data collected and analyzed for this study is not publicly available.

Author Contributions

All authors provided significant contributions to all essential aspects of the study. SR and GP completed the study development and collected the data from the study. Data organization and statistical analysis were completed by authors SR and NB. SR led the dissemination in the form of manuscript development. GP and NB provided substantial contributions to the manuscript's development, and all authors approved it.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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