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Original Research

The Effect of Body Armor on Repeated Sprint Performance and Inspiratory Muscle Strength

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Abstract

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Tactical athletes (law enforcement, military, firefighters, etc) face physically demanding occupational duties, often while wearing body armor that could compromise their exercise performance. It is unknown how wearing body armor influences exercise performance and whether exercising while wearing body armor influences the inspiratory muscle's pressure generation capabilities. Therefore, the purpose of this study was to examine how body armor affects repeated sprint performance and inspiratory muscle strength. Twelve college-aged males (n=12) performed the 35-m Running Anaerobic Sprint tests under three conditions (control [CNTL], unloaded plate carrier [UNL], and loaded plate carrier [LOAD]). Participants had their maximal inspiratory pressure recorded pre- and post-sprint tests. There were no differences between the conditions for inspiratory muscle strength during the pre-sprint test. Post sprint test, inspiratory muscle strength significantly increased ($p = 0.008$, $d = 0.26$) independent of condition. The small increase could be due to an acute potentiation effect brought upon by the high-intenstiy sprinting with short recovery. The LOAD condition had a large, statistically significantly higher total running anaerobic sprint test time ($p < 0.001$, $d = 1.5$) with a repeated sprint performance that was ~10% slower than the CNTL. A loaded plate-carrier body armor reduces repeated sprint performance but does not affect inspiratory muscle strength. Tactical athletes should aim to train with their style of body armor to reduce the adverse effects of wearing body armor during repeated anaerobic activity.

Keywords: Tactical strength and conditioning, torso-borne loads, respiratory muscles, exercise performance

Introduction

Most modern, life-threatening engagements by military and law enforcement occur in urban environments where running speed is critical to potential injury and effectiveness. These "tactical athletes" are equipped in body armor to protect their vital organs from gunshots and shrapnel; however, the additional weight can increase the physiological demand of locomotion.[1,2] This increase in physiological demand decreases agility,[3,4] task performance,[5–7] and can alter gait mechanics.[1,8,9] Further, body armor can decrease submaximal aerobic capacity by ~11% and increase perceived exertion by 5 -10% more.[1,2,6,10] However, it is unclear how wearing body armor affects repeated high-intensity sprint performance. Previous studies investigating the effects of body armor on exercise performance have focused on long-duration tasks or maximal-effort

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occupational tasks. However, in real-life operations, tactical personnel may not have the ability to rest in between bouts of high-intensity exertions for more than a few seconds. Understanding how this short recovery time combined with the additional load posed by body armor influences exercise performance may help with training these tactical populations to perform repeated bouts of high-intensity activity with minimal recovery periods.

While adding additional weight to the torso has been shown to increase a tactical athlete's overall work rate, body armor also restricts the chest wall[11–13], potentially impacting the force-generation capabilities of the inspiratory muscles. The primary inspiratory muscle that would be affected by the chest wall restriction would be the external intercostals; however, more rigid body armor styles, such as plate-loaded, can restrict abdominal expansion and possibly fatigue the diaphragm.[11,13,14] Body armor-related chest wall restriction can lower forced vital capacity (FVC) by ~16%, maximal oxygen uptake by ~8%, and worsen task completion time by ~11%.[2,11-13,15,16] These performance and pulmonary function detriments linked to wearing body armor are attributed to two potential mechanisms: 1) chest wall restriction and 2) added weight load to the torso. Both of these mechanisms could potentially reduce inspiratory muscle strength and improve our understanding for how wearing body armor reduces exercise performance especially in the conduct of high-intensity physical tasks that are associated with greater ventilatory demand. Therefore, the purpose of this study was to examine how wearing unloaded and loaded body armor during repeated, high-intensity sprints affects inspiratory muscle strength and athletic performance. We hypothesized that wearing unloaded and loaded body armor during repeated sprints would reduce exercise performance and inspiratory muscle strength, with worse outcomes during the loaded body armor condition.

Methods

Participants

A cross-sectional examination of repeated sprint performance and inspiratory muscle strength was conducted on college-aged, recreationally active men. Repeated sprint performance was measured with the Running Anaerobic Sprint test (RAST) using laser timing gates.[17] The use of a more linear protocol, like the RAST, was used to test the anaerobic effects on the participants rather than their agility or task completion skills. Inspiratory muscle strength was assessed using maximal inspiratory pressure (MIP) test pre-and post-sprinting.

Fifteen college-aged men were recruited from the university student body. Participants were recreationally active for the past year with no lower body injuries six months before testing. A minimal sample size of 12 was estimated *a priori* using G*Power (version 3.1.9.2) using an effect size in sprint performance of $d = 0.5$, $\alpha = 0.05$, power of 0.80, correlation 0.5, and nonsphericity correction of 1 for a one-way ANOVA with three conditions. Participants were required to be physically active for at least one year and be injury-free for six months before participation. A Physical Activity Readiness Questionnaire (PAR-Q) and health history questionnaire were used to establish whether they met these qualifications and to ensure that they were not at increased risk of events during exercise. The local Institutional Research Board granted ethical approval (IRB#1237954-3) according to the Declaration of Helsinki, and all participants provided written informed consent before participation in the study. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science.[18]

Protocol

Day one consisted of the participant providing written informed consent, completing the PAR-Q, and health history questionnaire and having their height and weight measured via scale and stadiometer (Seca mBCA 514, Seca North America, Chino, Ca, USA). The procedures and results for spirometry and plethysmography tests completed at baseline were previously reported.[19] Days 2-4 consisted of performing a MIP test followed by a RAST under three conditions. The control condition (CNTL) had participants wearing their basic athletic attire. The no plates condition (UNL) had participants wearing a plate-carrier (2.4 kg) (SBT Banshee elite 2.0 plate carrier, Shellback, Cayce, SC, USA) with no additional weight added to the vest. The loaded condition (LOAD) included the plate-carrier, ballistic plates, and dummy rifle magazines (14 kg total weight). The LOAD conditions weight was provided by Level IV front and back plates (3.7 kg each), and two side plates (1.1 kg each) (RMA Armament, Centerville, IA, USA) with an additional four weighted replica rifle magazines (0.5 kg) (AR15/M16/M4 30 RD. MAG, Ring's Manufacturing, Melbourne, FL). Participants put on the fully loaded carrier on day one to become familiar with the weight and fit. The carrier was tightened to the participants' preference. They were instructed that the fit should be secure enough to run in, but should not feel so tight that normal breathing feels encumbered. All three conditions were completed in a random order, which was counterbalanced to reduce potential order effects. The first condition began with control; then a coin flip determined the order of the other two conditions. This sequence was repeated for subsequent participants, with UNL and LOAD used as the first condition, respectively.

The maximal inspiratory pressure (MIP) test was performed in a standing position using a POWERbreathe device (POWERbreathe plus™, International Ltd, Warwickshire, United Kingdom).[20] Participants were instructed to exhale to residual volume with a tight seal around the mouthpiece, followed by a maximal inhalation lasting between one and two seconds.[21] This maneuver was performed three to seven times to ensure reproducible results. A valid test required three maneuvers to be within 10% of each other. The best measurement was recorded for analysis.

On days 2-4, participants performed the MIP test protocols before and after the RAST. On the days including the plate carrier, the participant put it on before the pulmonary tests and wore it without making any adjustments to the fit until the final MIP was performed. After the participants finished the MIP tests, they walked to an outdoor, marked-off course to perform the RAST. Two lanes, set side-by-side on level pavement, were marked off (Figure 1). Laser timing gates (Dashr Timing System™, Dashr Motion Performance Systems, Lincoln, NE, USA) were placed at the start and stop lines set 35-m apart in both lanes. There was at least 20-m of additional space at both ends to allow for deceleration after the sprints. Participants were given 10-minutes to perform a self-selected warm-up before running two 35-m sprints at half speed with a 10-second rest between runs. Before running the test, temperature, humidity, and wind speed were collected using a portable barometer (Kestrel™ 3500 Weather Meter, Kestrel Meters, Boothwyn, PA, USA). After the participant had been given one-minute rest, they performed the RAST. The test involved running six 35-m sprints with 10-seconds rest between each sprint (Figure 1). Participants were given a verbal countdown during every rest period to ensure they were back to the start line and were ready for the next sprint. Researchers gave verbal encouragement during every sprint. After the sixth and final sprint was finished, the participant was taken back inside the lab to perform another MIP test. This post-sprint MIP took place between 1.5 – 2 minutes after the participants finished their sixth sprint.[22]

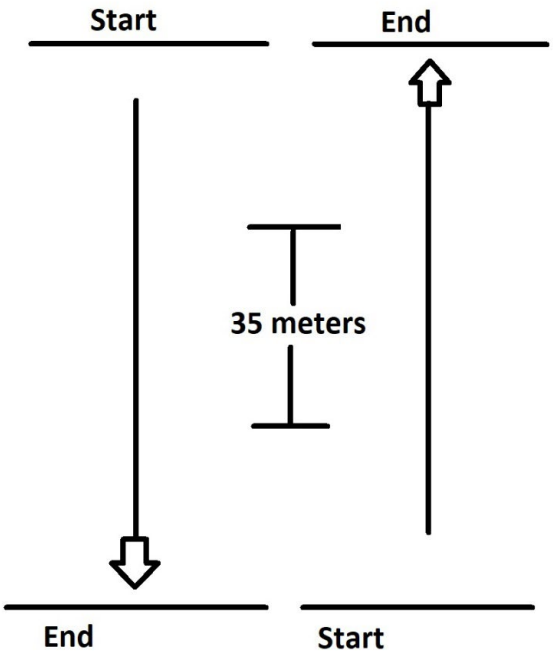


Figure 1. Running Anaerobic Sprint Test setup.

Statistical Analysis

All statistical analysis tests were performed using JASP (version 0.14) and statistically significant differences were accepted at a probability level of $p < 0.05$. Three one-way repeated-measures analyses of variance (ANOVA) were conducted to assess the differences among the three conditions (Control, UNL, LOAD) for RAST total time, split time, and MIP (pre- and post-). When the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. When a significant main effect was identified, pairwise comparisons were conducted using a Bonferroni adjustment to determine which conditions differed.

Since the RAST test was performed outside, an analysis of covariance (ANCOVA) was used to examine the differences in RAST total time while controlling for environmental factors (temperature, wind, and humidity).

Effect sizes are reported as Cohen's *d*, and interpreted as <0.2 = trivial, 0.2 = small, 0.6 = moderate, 1.2 = large, 2.0 = nearly perfect, >4.0 = extremely large.[23]

Results

Three participants were excluded after their first visit due to their inability to obtain consistent pulmonary function test results according to the American Thoracic Society's guidelines.[24] Twelve participants (age: 25 ± 4 years; height: 179.3 ± 7.5 cm; weight: 80.7 ± 21.2 kg) were included in the final data analysis.

Mauchly's test indicated violations of sphericity; therefore, Greenhouse-Geisser corrections were applied to a two-way analysis of variance. After the correction, there was a small, non-significant interaction effect for conditions x split times, $F(3.2, 34.7) = 2.208$, $p = 0.102$, $\eta_p^2 = 0.167$. An analysis

of variance of split times across the three conditions showed a large effect size and was statistically significant, $F(1.6,17.1) = 28.72$, $p < 0.001$, $\eta_p^2 = 0.723$. Post hoc analyses using the Bonferroni post hoc criterion for significance indicated that split 1 was significantly slower ($p < 0.001$) than split 3 ($d = 0.8$), 4 ($d = 1.2$), 5 ($d = 1.5$), and split 6 ($d = 1.7$). Split 2 was significantly slower ($p < 0.001$) than split 4 ($d = 0.9$), split 5 ($d = 1.2$), and split 6 ($d = 1.3$). Split 3 was significantly slower than split 5 ($p = 0.003$, $d = 0.7$) and split 6 ($p < 0.001$, $d = 0.9$) (Figure 2).

An analysis of variance of total run time across the three conditions showed a large effect size and was statistically significant, $F(2,22) = 54.76$, $p < 0.001$, $\eta_p^2 = 0.833$. Post hoc analyses using the Bonferroni post hoc criterion for significance indicated that total running time was significantly higher in the LOAD condition (40.00 ± 2.33 sec) than in both the CNTL (36.00 ± 3.01 sec, $p < 0.001$, $d = 1.5$), and UNL (36.00 ± 3.00 sec, $p < 0.001$, $d = 1.5$) (Figure 3).

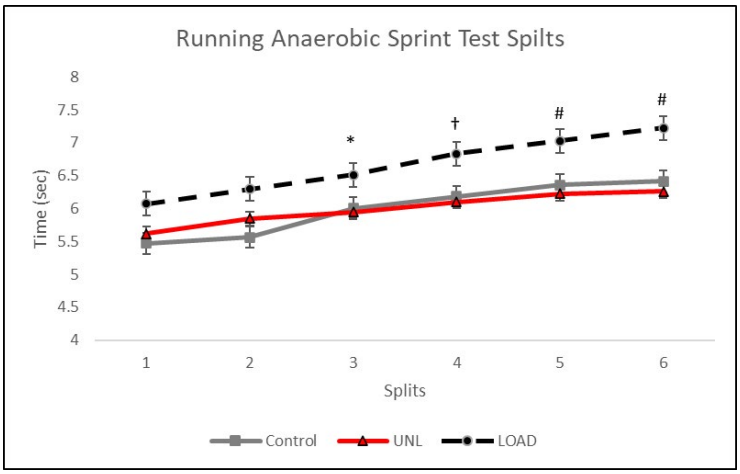


Figure 2. Running Anaerobic Sprint Test split times.
* indicates a significant pairwise difference compared to split 1 ($p < 0.001$)
† indicates a significant pairwise difference compared to split 1 and 2 ($p < 0.001$)
# indicates a significant pairwise difference compared to split 1, 2, and 3 ($p < 0.01$)

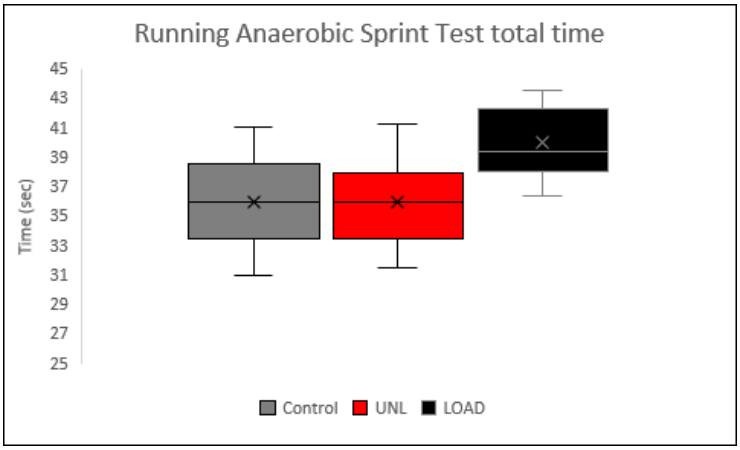


Figure 3. Running Anaerobic Sprint Test total time.
* indicates a significant pairwise difference compared to Control and UNL ($p < 0.05$)

A two-way analysis of variance yielded small, non-significant interaction effects for MIP x condition, $F(2,22) = 1.049$, $p = 0.367$, $\eta_p^2 = 0.087$ (Figure 4). There was a main time effect for MIP, $F(1,11) = 10.25$, $p = 0.008$, $\eta_p^2 = 0.482$, such that post-run MIP was significantly greater (155.0 ± 31.0 cmH_2O) than pre-run (147.2 ± 29.5 cmH_2O), yet the magnitude of this difference was small ($d = 0.26$).

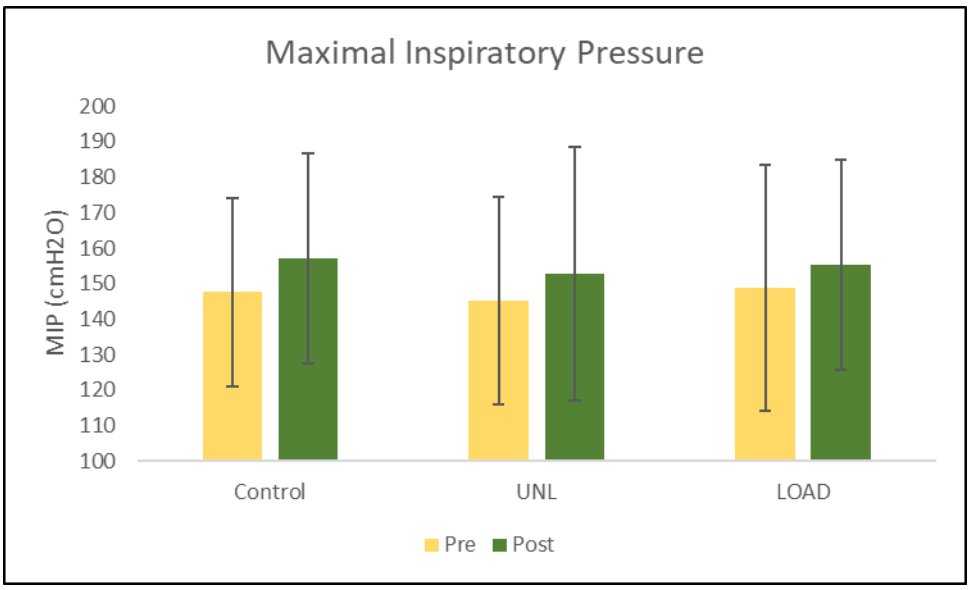


Figure 4. Maximal inspiratory pressure pre-and post- sprint test.

An ANCOVA revealed significant main effects of wind, $F(1, 30) = 14.33$, $p < 0.001$, $\eta_p^2 = 0.323$, and condition, $F(2, 30) = 13.83$, $p < 0.001$, $\eta_p^2 = 0.480$. Temperature, $F(1, 30) = 1.88$, $p = 0.180$, $\eta_p^2 = 0.059$, and humidity, $F(1, 30) = 1.76$, $p = 0.195$, $\eta_p^2 = 0.055$, were not significant predictors of total time.

Discussion

The purpose of this study was to examine how wearing unloaded and loaded body armor during repeated sprinting acutely affects sprint performance and inspiratory muscle strength. Results indicated RAST performance was ~10% slower in the LOAD condition compared to the CNTL and UNL. Contrary to our hypothesis, the UNL condition was not associated with reduced performance or inspiratory muscle strength. Additionally, sprinting with and without body armor appeared to paradoxically increase post-sprint inspiratory muscle strength suggesting that sprinting with body armor was not associated with inspiratory muscle fatigue but may in fact potentiate the force generation capabilities of the inspiratory muscles.

Unloaded body armor was expected to provide minimal chest wall restriction while providing a stimulus of wearing body armor.[1,11] Loaded body armor was expected to provide both chest wall restriction and an additional metabolic load. Using a plate carrier style loaded body armor decreased repeated-sprint performance by ~10%. This decreased performance was not observed in the UNL condition. Decreased performance has been shown in similar studies involving body armor and task performance.[1,2,6,8] Larsen et al. found a similar 10% reduction to task completion while running a circuit course in full combat loads (helmet, training rifle, body armor); however, this performance decrease did not progress after repeated runs of the course.[6] In addition to a decrease in task performance, there is a demonstrated inverse relationship between body armor weight and physical performance.[10] The load used in the current study (14 kg) is heavier than many previous studies, but did not exceed the weight used by Larsen.[6] We found no difference between the changes in individual split times independent of the condition, which could indicate that body armor was insufficient to increase the test's sprint fatigue rate. A decrease in overall performance without increasing fatigue rate while wearing body armor has been demonstrated before in the literature during short-duration occupational tasks and athletic performance.[6,25]

Additionally, our results may reflect only college-aged, recreationally trained males with no prior experience wearing plate carriers during exercise. Future research should examine differences across populations with varying experience levels to determine whether the decrease in performance during short, high-intensity running is purely due to increased load or reflects a skill component.

A decrease in short-duration, high-intensity exercise performance while wearing loaded body armor indicates that some physical training should include wearing body armor while performing similar tasks the tactical athlete may encounter. Considering we found a decrease in performance only in the LOAD condition and no difference in post-run MIP, it is likely pulmonary function has a minimal effect on short-duration, high-intensity sprinting. Adding loaded body armor during training will increase overall training volume and would likely increase the tactical athlete's ability to maneuver under the load. Running under an additional load can also increase the time to accelerate and decelerate, modify the athlete's center of gravity, and affect lower-body kinematics.[2,8,26] These modifications may be addressed if the athlete trains under the additional loads they wear during their duties. Becoming more accustomed to their occupational loads can improve the perception of exertion and breathlessness, even if the load increases.[27] Additionally, while wind was shown to be a covariate for RAST total time, the values were low (Control: 0.75, UNL: 0.65, LOAD: 0.65 kph), and the bidirectional protocol would negate most of the effect.

Research has extensively studied the decrease in inspiratory muscle strength, commonly referred to as inspiratory muscle fatigue (IMF), in various physical activity events over long periods.[28–35] Due to the high demand for oxygen and the elimination of CO_2, the prolonged increase in respiratory rate during aerobic activity should be the most common activity for IMF to occur. However, anaerobic activity, especially when a torso-borne load is involved, may still elicit IMF in a shorter amount of time due to an increase in respiratory rate to eliminate CO_2 and provide oxygen for the re-synthesis of PCr.[36,37] A small number of studies have examined anaerobic activity and the IMF, but there is almost no research on how a torso-borne load may influence anaerobic activity. Ohya et al. found that a single 400-meter sprint was enough to decrease MIP in elite female runners by 10%, with an even greater decrease of 15% during an 800-m sprint.[22] Ohya et al. is one of the few studies that has demonstrated a decline in MIP after an anaerobic activity; however, it is unclear if similar results would be seen after repeated bouts of shorter duration sprints.

Based on our results, the IMF does not appear to occur after a short, high-intensity repeated sprint protocol. MIP showed a significant yet small increase post-RAST independent of the condition (d = 0.26). This increase may be caused by a slight post-activation potentiation effect on the inspiratory muscles. The potentiation from doing a short, non-fatiguing activity immediately before another activity has been well established in different anaerobic and resistance training activities. However, it has not been observed in the respiratory muscles.[38–40] This increase in MIP post-exercise may indicate that anaerobic activity could also elicit a training response to the respiratory muscles. Previous literature has shown that while endurance athletes have higher MIP compared to untrained and power athletes, power athletes also had greater MIP than untrained individuals (d = 1.12).[41] The possible potentiation effect of the respiratory muscles due to short, high-intensity sprints should be studied further to determine at what point the potentiation effect may occur, and when fatigue may set in.

Our study found that using plate-carrier-style body armor leads to a ~10% decrease in repeated sprint performance; however, the rate of fatigue from sprinting was not significant (η^2 = 0.025) between conditions. Tactical athletes should wear whatever style of body armor they may need

during their occupational duties during training to improve their experience while under the additional weight and thoracic cavity restriction. However, to avoid overuse injury, limiting load-carriage sessions to once every 10-14 days, with loads comparable to the individual's normal occupational loads, is recommended.[42] Overall workout volume should be adjusted to accommodate the additional increase in work rate caused by the body armor.

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