The Soldier's Heavy Load

By Lauren Fish and Paul Scharre

Center for a
New American
Security

ABOUT THE AUTHORS

Lauren Fish is formerly a Research Associate with the Defense Strategies and Assessments Program at CNAS.

Paul Scharre is a Senior Fellow and Director of the Technology and National Security Program at CNAS.

ABOUT THIS REPORT

This report, the fourth in the *Super Soldiers* series, covers findings of the Center for a New American Security's study on dismounted soldier survivability. This report is in response to a study conducted for the Army Research Laboratory to identify future concepts and technologies to improve soldier survivability and effectiveness over the next 20-30 years in order to identify high-payoff science and technology investment areas. While the primary audience for this report is the Army science and technology community, the report's findings and recommendations may be of interest to a broader group of stakeholders, including across the Army, the Joint Force, and the wider defense community. The full series can be found at www.cnas.org/super-soldiers.

Views expressed in this report are of the authors alone. CNAS does not take institutional positions.

Some data in this report includes weights for the Army's older body armor system, the Improved Outer Tactical Vest (IOTV) and older helmets. The Army is in the process of replacing the IOTV with a lighter system, which weighs 27 pounds for torso body armor plus helmet. For more details on the evolution of body armor and weight reduction goals, see the earlier report in the *Super Soldiers* series, "Soldier Protection Today."

Executive Summary

Body armor saves lives. Modern body armor has given U.S. troops an unparalleled advantage on the battlefield, improving survivability and reducing casualties. This protection comes at a price, however. U.S. ground troops today carry an average of 27 pounds of personal protective equipment (body armor and helmet). This weight comes on top of an already heavy burden consisting of a weapon, ammunition, water, batteries, and other gear. Surveys from recent wars have found dismounted ground combat troops carrying 90 to 140 pounds or more in combat. Heavy loads reduce mobility, increase fatigue, and reduce mission performance.

This report, the fourth in the *Super Soldiers* series, examines the heavy burden of dismounted ground combat troops. It recommends a paradigm shift for thinking about survivability, balancing the benefits of increased protective equipment and other gear against its costs in weight and reduced mobility and performance. The report concludes with recommendations for adjustments to policies and equipment to improve overall survivability.

Key Findings

- The heavy weight and bulk of body armor decreases soldier performance.
- Experiments have demonstrated that heavy loads affect mobility and situational awareness, leading to a measurable decrease in shooting response time.
- Because dismounted soldiers are limited by what they can physically carry into battle, soldiers face tradeoffs between mobility, protection, and lethality. Heavier loads also increase fatigue and can reduce mission performance overall.
- A paradigm shift is needed from a narrow focus on protection to considering overall soldier survivability.
- The benefit of additional armor should be balanced against its effect on mobility, survivability, and mission performance.
- Soldiers have always carried heavy weight into combat, but today's excessive weight burden has severe consequences for combat performance, cognition, and injury.
- Additional weight reduces cognitive and tactical performance and mobility, but the Army has not commissioned an authoritative assessment to tie weight to measures of operational effectiveness.
- Technology often increases, rather than decreases, the load of the soldier.
- Army and Marine Corps doctrine acknowledges the harmful effects of excessive weight, but in practice historical guidelines for weight limits are not followed.
- One problem is that research studies frequently tie heavier loads to slower soldier movement, but often do not take the next step to link loads to measures of operational effectiveness, such as marksmanship, maneuver, or exposure to enemy fire.
- Commanders do not have actual or perceived authority to change the level of protection based on conditions on the ground.
- Current body armor is over-designed.
- Optimizing body armor requirements for injury criteria and threat could reduce weight.
- Tailoring body armor for individual soldiers could potentially increase area coverage, improve mobility, and reduce weight.

Recommendations

The Army should:

- Launch an authoritative study to better assess the relationship between load and combat effectiveness, building on existing literature.
- Undertake a thorough assessment of necessary supplies and the fidelity of timely resupply, and educate leaders on the importance of minimizing loads.
- Clearly delegate authority to company-level commanders to modify the level of protection as needed, based on the specific threat and mission.
- Optimize body armor requirements for the actual threat environment and not over-design body armor to protect against unrealistic combinations of threats, adding unnecessary weight.
- Conduct an assessment of the feasibility of tailored body armor and potential advantages in reduced weight, increased area coverage, and improved mobility. This assessment should include an evaluation of manufacturing methods to reduce the cost of adopting individually tailored solutions at scale.

The Burden of Armor

Body armor provides increasingly advanced protection, but at a cost in soldier performance. Body armor is heavy, bulky, and hot. It has the immediate effect of hampering soldier mobility by adding weight, limiting joint mobility, and restricting movement in tight windows, doorways, and vehicles not designed for the bulk of modern armor. Additionally, armor traps heat, increasing soldier thermal load, a particular concern in hot environments. By contributing to overall soldier load, armor also restricts visibility, reduces situational awareness, and delays response times. Cumulatively, armor's weight, bulk, and thermal load increases soldier fatigue and reduces physical and cognitive performance.

Increased soldier load not only slows movement and increases fatigue, but also has been experimentally demonstrated to decrease situational awareness and shooting response times. Heavy loads decrease situational awareness by tilting the head at a downward angle and increasing the amount of weight that has to be controlled when a soldier stops quickly.[1] In controlled experiments, loads also have been demonstrated to adversely affect shooting response times, increasing the time it took soldiers to fire accurately by 0.1 second relative to unloaded conditions.[2] Further, experiments involving soldiers wearing different sizes of armor indicate large armor can lengthen the time between acquiring and acting on a series of targets. Wearing a smaller size of body armor than advised resulted in speeds similar to the baseline without body armor, but when wearing the advised size of body armor, the time to engage two targets lengthened by 0.2 seconds. The overall time to complete a five-target task extended by up to 0.7 seconds, from 6.3 without body armor to 7 seconds when wearing standard fit body armor.[3] Together, these studies show that dynamic marksmanship, where the ability to stop and acquire a target is critical, is compromised by heavy weight and bulky loads.

Armor takes this heavy toll on soldier performance without adding any benefit to the soldier until the moment of impact. As Army researcher Dr. James Q. Zheng explains, "Body armor is essentially parasitic weight; it contributes nothing to the soldier's operational effectiveness until the moment it is required to resist a potentially lethal threat."[4] This is not to suggest that body armor is not effective in stopping ballistic threats or is not valuable. Indeed, body armor saves lives. However, it also comes with a heavy burden. Body armor increases protection but decreases soldier performance.

The "Iron Triangle" concept, often applied to ground vehicles, captures this challenge. The "Iron Triangle" represents the tradeoff between mobility, protection, and lethality. Since there is a limit to the weight a vehicle can support, any increase to one of the variables results in degradation in the others. Dismounted soldiers face a similar challenge. They must physically carry every piece of equipment they have into battle. This means that any improvements in protection or lethality that add weight reduce mobility. Mobility can be regained by reducing soldier weight and equipment, but generally at a cost in protection or lethality. Thus, soldiers remain trapped within the Iron Triangle.

Mobility is an important factor in mission effectiveness and survivability. Maneuver increases the chances of avoiding enemy contact or initiating contact on one's own terms. Extra weight may in fact lead to engagements that otherwise could be avoided through mobility.[5] Further, unlike ground vehicles that do not tire over a mission, soldiers fatigue. The consequences of supporting heavy weight while moving result in diminished cognition, responsiveness, and decision-making. A narrow focus on protection alone can be harmful. Soldier survivability is about more than just protection. Survivability encompasses situational awareness, mobility, and lethality as well. Finding the enemy, outmaneuvering them on the battlefield, and attacking first is the most ideal situation for ensuring soldier survivability.

Enhancing soldier *survivability* goes beyond simply focusing on improving protection – those protective improvements must be balanced against their cost in mobility and lethality. More body armor is not always better. The weight of body armor should be holistically balanced against its cost in mobility, situational awareness, and soldier performance.[6]

The Soldier's Heavy Load

Body armor is but one element of a soldier's heavy load. Soldiers have long carried heavy burdens into war, but today's soldiers carry an unprecedented amount of weight. For the last 3,000 years, dismounted soldiers carried 55 to 60 pounds on average.[7] This has almost doubled in the last 200 years. Roman legionnaires carried almost 60 pounds.[8] The British fighting in the American Revolutionary War carried 80 pounds. At the Battle of Waterloo (1815), the British carried 60 to 70 pounds while the French carried 55 pounds. The French in the Crimean War (1853-1856) carried 72 pounds. Around World War I, approximate march weights jumped to 85 pounds. U.S. soldiers trained with at least 60 pounds but carried additional rations and munitions in combat.[9] During World War II, U.S. troops carried more than 80 pounds in the Normandy landings.[10] U.S. soldier loads increased even more dramatically in the second half of the 20th century. March loads stayed at approximately 80 pounds during Vietnam but grew to 100 pounds afterward, with a maximum march weight over 160 pounds in Grenada in 1983.[11] In Iraq and Afghanistan, march weights have approximated 100 pounds or more.

The increased weight load carried is not matched with an increased ability to support it. Access to reliable nutrition in the 18th and 19th centuries improved fitness outcomes and average heights. Americans had better nutritional supplies, which produced Americans taller on average than their European counterparts, but growth rates slowed in the 1950s as the plentiful U.S. diet became less nutritious, leading to increased obesity.[12] The U.S. population has since become the heaviest globally. The average American man aged 30 to 39 is just shy of being considered obese on the Body Mass Index (BMI) scale.[13] This trend has not been isolated to the civilian population. Increasing numbers of servicemen and women are obese, including 6.7 percent of the combat population in 2015, a significant increase from approximately 1 percent in 2001.[14] Although significantly lower than the estimated 70 percent of the American population that is obese, nearly 8 percent of the overall force classifies as such.[15] Of the broader population, 31 percent of Americans of a military age are too overweight to qualify for military service.[16] Additionally, trends indicate today's young men are weaker than previous generations[17] as measured by grip strength, which has been shown to be an effective evaluating mechanism of strength and endurance.[18] These trends indicate that natural physical improvements in the amount of weight that future soldiers can carry are unlikely.

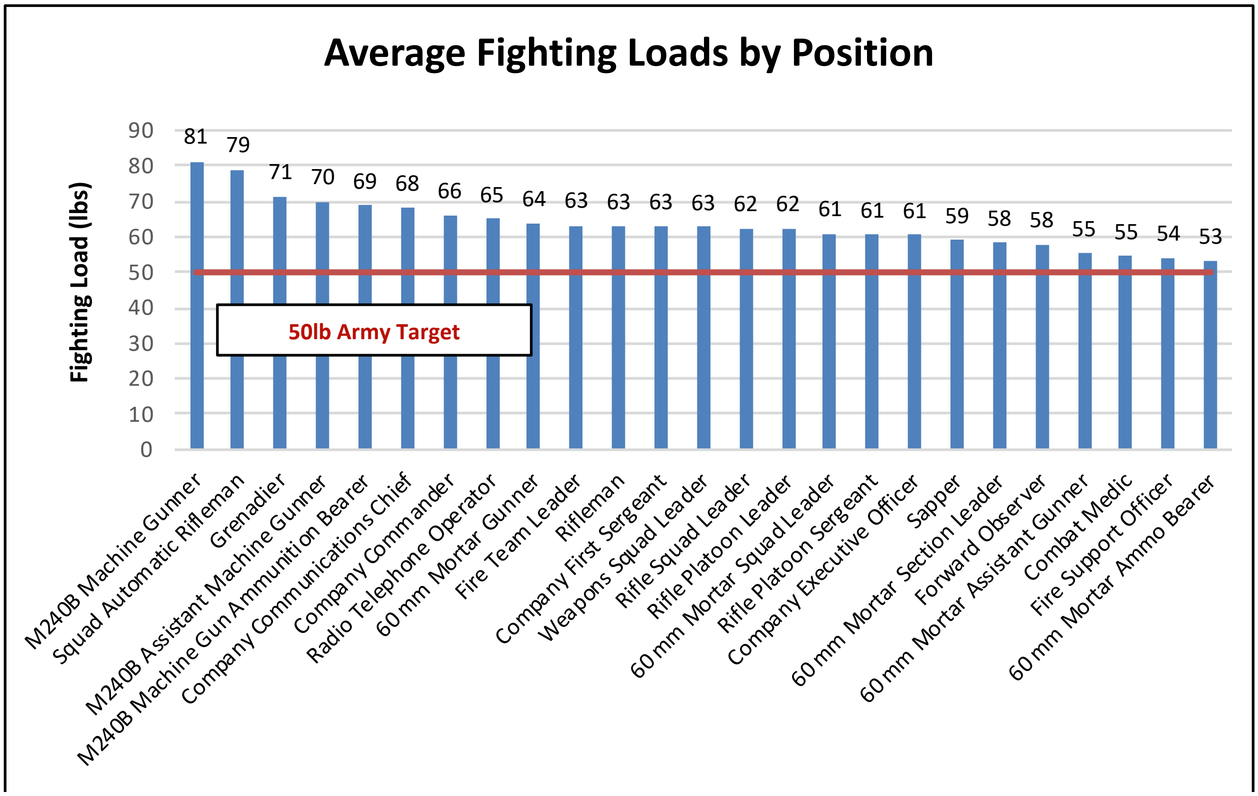
Fighting load consists of the equipment (weapon, ammunition, helmet, body armor, water, etc.) that soldiers carry directly on their person while maneuvering and fighting.

Approach load consists of the fighting load plus a rucksack carried during a march, which would contain additional water, ammunition, food, and other supplies for the duration of the mission.[19]

The Marine Corps includes performance measures in their load definitions. For the equivalent of a "fighting load," the average infantry Marine should "be able to conduct combat operations indefinitely with minimal degradation in combat effectiveness." The "approach load" equivalent should still allow a Marine to march 20 miles in eight hours "with the reasonable expectation of maintaining 90 percent combat effectiveness."[20]

Notional Individual Soldier Equipment	**Pounds**
Army Combat Helmet	6.5
Body Armor	33.2
2 armor plates (ESAPI)	12.5
IOTV	15.7
2 side plates	5
Weapon + Ammo (210 rounds)	
M4	5.9
M249	17
Ammo	7
Light Thermal Sight	1.9
Night Vision Goggles (PVS14)	1.4
Rucksack	8
Power Sources (Batteries: 3-day mission)	16
Comms/Radio (Leader Only)	
PRC148	1.9
PRC152	2.6
Rations (3-day mission)	
First Strike Ration	6
MRE	13.5
Other (Uniforms, water, personal hygiene, first aid, etc.)	19

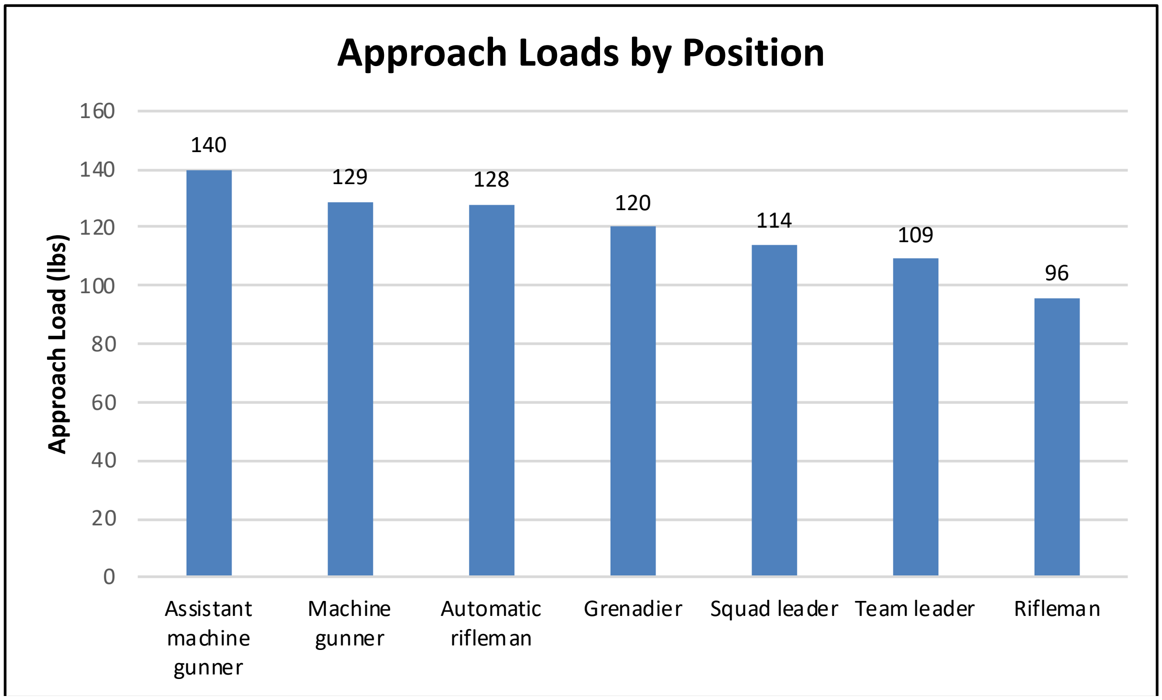
Soldiers would not carry all of the above equipment at once. For example, a soldier would not carry an M4 rifle and an M249 Squad Automatic Weapon. (Source: J. Q. Zheng and S. M. Walsh, "Materials, manufacturing, and enablers for future soldier protection," in Lightweight Ballistic Composites, 2nd ed., Woodhead Publishing, 2016.)



Combat load carried by position. Data is from 2003, but weight of armor has increased since then. (Source: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April-May 2003," (U.S. Army Center for Army Lessons Learned, 2003).)

The Harmful Effect of Heavy Loads

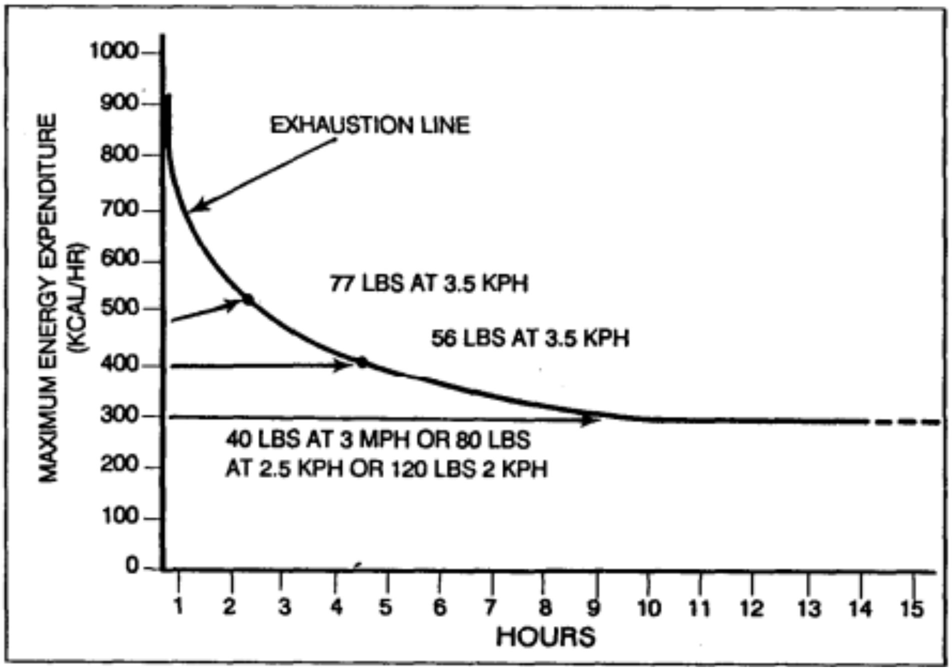
Today's soldier is heavily burdened. A 2003 battlefield combat load study found average fighting loads ranging by position from 53 pounds to 81 pounds.[21] The average approach march load was 102 pounds,[22] consistent with other average weights of around 90 pounds when a rucksack is included.[23] These weights, heavy as they are, may be increasing over time. A 2007 Marine study revealed an average load of 97 to 135 pounds in combat.[24] A 2017 Government Accountability Office report identified Marine loads of 90 to 159 pounds, with an average of 117 pounds, and Army loads of 96 to 140 pounds, with an average of 119 pounds.[25]



Data from 2006, U.S. Army. (Source: Government Accountability Office, "Personal Protective Equipment," GAO-17-431, May 2017, 9.)

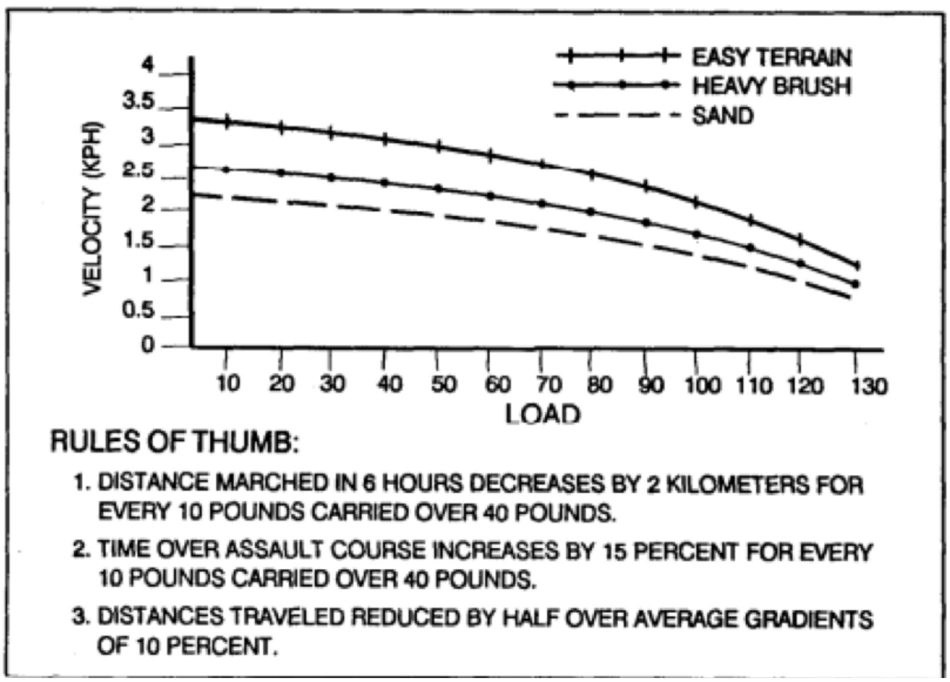
Heavy loads can diminish both cognitive and physical performance. Combat requires forces prepared for engagements along both metrics; anything that diminishes the ability to engage the enemy is suboptimal. Heavy weight decreases tactical capability, especially when combined with fatigue and the physical effects of combat stress.[26] Army doctrine reflects an understanding of the negative effect weight has on agility and physical performance. Army field manual FM 21-18, *Procedures and Techniques of Foot Marches,* encourages soldiers to carry heavier loads in training than combat in order to increase strength and improve maneuver on the battlefield.[27] Further, it advises that each additional 10 pounds of weight lengthens obstacle course completion time by 10-15 percent, and every 10 pounds over a 40-pound threshold decreases distance marched over six hours by 2 kilometers.[28] FM 21-18 details that an eight-hour march should cover 32 kilometers (almost 20 miles) at 4 kilometers per hour.[29] An unpublished Army study demonstrates this is possible with a 30-pound load, but with a 70-pound load, marching progresses only 15 miles in eight hours. At 110 pounds, troops move less than 10 miles in an eight-hour period,[30] half the expected march rate. Similar tests show the distance traveled by a rifleman decreases 35 percent when carrying the current weight of 95 pounds compared to the 50-pound goal, shortening the distance traveled in eight hours from about 17 miles to 11 miles.[31]

Time to Exhaustion as a Function of Soldier Load and Speed



Under heavier loads, soldiers reach exhaustion faster, unless they move slower.
(Source: Army Field Manual 21-18, Procedures and Techniques of Foot Marches, page 5-5)

Soldier Speed as a Function of Load and Terrain

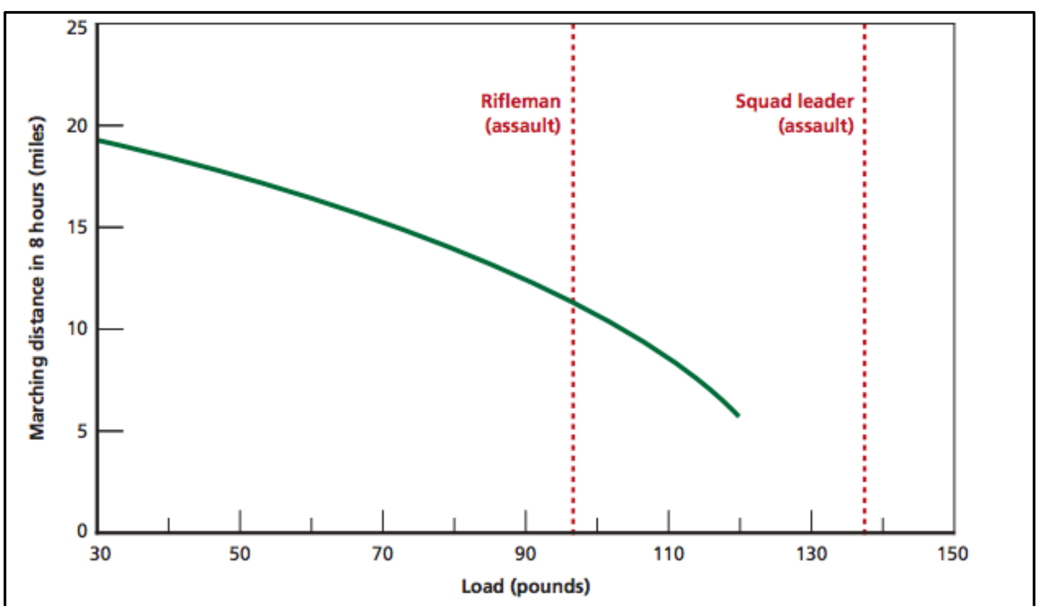


Under heavier loads and in more adverse terrain, soldiers move slower.
(Source: Army Field Manual 21-18, Procedures and Techniques of Foot Marches, page 5-5)

While the Army conducts regular human performance studies, they are not used to conclusively determine the effects of heavy loads on operational performance. It is not possible to perfectly simulate a combat environment and the requisite stress during testing for a completely realistic assessment. Nevertheless, findings from Army studies permit some conclusions. Heavier loads decrease stamina, strength, acceleration, and agility, and lengthen obstacle course completion times.[32] Time to complete a 10-station obstacle course – including agility and balance tests, sprinting, stair and ladder climbs, weight carriage, and crawling – increased by 15 percent when carrying a 44.3-pound load (relative to an unloaded configuration wearing uniform alone) and 41 percent when carrying 79.3 pounds.[33] Further, more weight requires higher caloric expenditure, causing fatigue over time.[34] These effects have negative operational effects, as shown in the increased time it takes to complete tasks and quicker onset of fatigue.

Carrying heavy loads, and body armor specifically, requires more oxygen but decreases the ability to inhale it. When supporting 100 pounds, studies showed power output and overall oxygen consumption decreased.[35] The effect of higher loads increases non-linearly; the effect at approximately 100 pounds was greater than expected based on lighter testing.[36] Further, weight from wearing a backpack caused a "significant rise" in respiratory fatigue measurements, which could limit extreme physical activity, according to a study in the *Journal of Applied Biomechanics*.[37] Similarly, a study published in *Aviation, Space, and Environmental Medicine* found that weight on the body, including body armor, can "[impair] respiratory muscle function and [increase] respiratory muscle work." As breathing becomes harder, fatigue is more likely, and exercise tolerance is limited.[38] While heavy weight has disproportionate respiratory consequences, these effects are not exclusive to big loads. In another study with weights below 35 pounds, body armor specifically caused reduced pulmonary function.[39] Some of the negative effects can be addressed through training respiratory muscles. Studies have shown better low-intensity activity and high-intensity performance times due to improved inspiratory muscle strength after exercising with a 55-pound backpack.[40]

Soldier Distance as a Function of Load Carried



Soldiers march less distance in the same time under increased weight. Conditions are for a soldier weight of 171 pounds, walking on dirt with a 1 percent grade, and a work load of 350 Kcal/hour. (Source: Unpublished findings from a 1988 Army study by R.F. Goldman shown in Lightening Body Armor, RAND Corporation.[41] Reprinted with permission.)

Strength and exertion are also negatively affected by heavy weight. Studies have shown reductions in the power exerted and stamina with even a 55-pound load.[42] Weight decreases acceleration under even a modest 50-pound load, less than most servicemembers wear in combat. In studies, 30-meter sprint times increased, but most of the increase was in the initial 5 meters where acceleration occurs.[43] There is also an effect on agility in unanticipated movements.[44] A report in the *Military Medicine* journal explained that while wearing body armor:

> men performed 61% fewer pull-ups and women's hang time was reduced by 63%; stair stepping was reduced by 16% for both men and women. [Body armor] significantly impacted the physical work capacity of militarily relevant tasks … The potential for physical exhaustion is high and performance of physical tasks is markedly impaired when wearing [body armor].[45]

Finally, situational awareness is degraded by heavy weight, hurting operational performance by making soldiers more susceptible to gunfire and lengthening reaction times. Under simulated enemy fire, heavy weight modestly slowed reaction times, increasing exposure and reducing the ability to move quickly away from enemy contact. Increased susceptibility to enemy fire was demonstrated to be a function of the load carried.[46] The time required to determine and acquire a target increased under heavy loads from just over 3 seconds to more than 3.5 seconds in some configurations, as accuracy decreased.[47] Further, soldiers on a 20-kilometer march reported increased fatigue under heavier loads and decreased alertness corresponding to the increased weight (assessed at 75 pounds, 105 pounds, and 135 pounds).[48]

In addition to the immediate harmful effects of heavy load on performance, supporting this weight for a prolonged period has deleterious effects. Data on servicemember injuries from the wars in Iraq and Afghanistan led researchers from the Naval Health Research Center to conclude that excessive loads may have exacerbated injuries.[49] Soldiers as young as 25 have retired due to degenerative arthritis from heavy loads.[50] Almost one-third of medical evacuations from the battlefields in Iraq and Afghanistan from 2004 to 2007 were due to spinal, connective tissue, or musculoskeletal injuries, *twice* those from combat injuries. This can limit servicemember careers, representing a loss in valuable institutional knowledge and force readiness. From 2003 to 2009, the number of retired Army soldiers with at least one musculoskeletal problem went up tenfold.[51] (These problems already cost the Department of Veterans Affairs $500 million annually in disability benefits, which is expected to grow.[52]) The risk of injury due to heavy loads also decreases the possible talent pool.

Soldier loads today are so severe that in fact Army researchers are hesitant to test soldier performance under full combat loads in medical experiments for fear of causing injury. The research cited above illustrates the effect of weight on elements of physical performance, but there is a dearth of research connecting this to measures of combat effectiveness. This lack of definitive Army testing linking load and combat effectiveness continues to provide the illusion that carrying heavy weight is cost-free, which perpetuates a lack of action in solving the problem.

The result is that soldiers often carry more into combat than is necessary. In WWI, 10 times as many rounds of ammunition were carried as were likely to be used. This ammunition quantity was not decreased after trucks and aircraft enabled front line resupply in WWII.[53] Many of the deaths at Omaha Beach were from drowning due to exceedingly heavy packs from overestimating what could be carried.[54] The Army permits carrying up to 120 pounds for an “emergency approach load” when resupply is not guaranteed but stipulates that contact with the enemy should be avoided under such heavily burdened conditions.[55] According to Army doctrine, commanders should determine mission-specific loads based on risk analysis, but exceeding the maximum load threatens mission failure.[56] Army FM 21-18 states:

> The ability of a soldier to march and fight is directly related to his load. The maximum individual load limit cannot be exceeded as an infantry soldier will not accomplish his mission. Soldiers fight light with only the equipment required for the immediate mission. They receive additional weapon systems and materiel when required.

Of course, in practice, the limits specified in Army doctrine – 48 pounds fighting load and 72 pounds approach march load – are routinely violated.

It's tempting to think that technological improvements may lighten the soldier's load, but historical experience suggests the opposite. Army historian SLA Marshall remarked in 1950 that technology has not "*decrease[d] by a single pound the weight the individual has to carry in war.* He is still as heavily burdened as the soldier of 1000 years B.C."[57] Sixty years later, SLA Marshall's observation remains just as true. Technology has only given soldiers even more to carry: night vision goggles, radios, laptops, advanced body armor, GPS devices, and other equipment. Improvements in materials technology have led to only marginal reductions in armor weight, while keeping pace with protection from emerging threats. Future enemy adaptation will likely require continued improvements in protection, which only increases weight.[58] Technological advances are not a silver bullet. The decisive element of combat must be protected: the soldier's ability to maneuver and engage the enemy.[59]

Officially, Army doctrine acknowledges the tradeoffs of heavy loads. FM 21-18 observes: "[T]he primary consideration is not how much a soldier can carry, but how much he can carry without impaired combat effectiveness – mentally or physically. The combat strength of a unit cannot be counted solely by the number of soldiers but must be counted by the number of willing and physically able soldiers."[60] As SLA Marshall argued, 5,000 rested, conditioned men will always defeat 15,000 fatigued men.[61] Army practice, however, often diverges from this aspiration, in Marshall's time and today.

Recommended Limits of Load Carriage

The deleterious effects of load have been recognized and embodied in consistent weight load recommendations, but these have not been heeded. Today's combat load far exceeds recommended limits, which have consistently approximated one-third of body weight, or 50 pounds. Research as far back as the late 1800s recommended a 48-pound limit.[62] Findings in the 1920s recommended a maximum of 40 to 45 pounds, arguing additional weight beyond one-third body weight would have disproportionate costs to the weight added.[63] Efforts in the interwar years between WWI and WWII targeted a weight under 35 pounds.[64] SLA Marshall proposed a maximum training load of one-third body weight, equating to 51 pounds, in 1950. He stipulated a lighter combat load, which he arbitrarily set as four-fifths of the training load or about 40 pounds.[65] In FM 21-18, the Army sets the maximum fighting load at 48 pounds and the maximum approach march load (which includes the fighting load) at 72 pounds.[66]

A 2003 Marine Corps load study assessed existing recommendations, including the Army recommendation, its source in the DoD Design Criteria Standard (MIL-STD-1472F), and deliberations with military scientists. These sources led the Marine Corps study to recommend setting fighting and approach loads at 30 percent and 45 percent of body weight, respectively.[67] In 2003, the average male Marine weighed 169 pounds, resulting in a maximum fighting load of 50.7 pounds (30 percent) and approach weight of 76.1 pounds (45 percent).[68]

Other sources also regularly cite the 50-pound number. The Naval Research Advisory Committee 2007 report recommended a 50-pound maximum assault load but cited six Marine duty positions with combat patrols exceeding that amount.[69] A 2001 Army study also recommended a 50-pound limit,[70] and General Eric Shinseki, as then-Army Chief of Staff, set a maximum 50-pound combat load goal by 2010.[71]

Recommendation by Source (in lbs)		
Year	Recommending Body	Fighting Load (lbs)
Late 1800s	German William Frederick Studies	48
1920s	Hygiene Advisory Committee of the British Army	40-45
1930s	British Aldershot Committee	35
1950	U.S. Colonel SLA Marshall	40
1990	U.S. Army FM 21-18	48
2001	U.S. Army Science Board Summer Study	50
2003	USMC Combat Load Report	50.7
2007	U.S. Naval Research Advisory Committee	50

The remarkably consistent standards are not adhered to by either the Army or the Marine Corps, and the trend is not positive that this will change. SLA Marshall reasoned that the continued heavy soldier load was due to a “general indifference” to the problem.[72] He concludes by praising the need for mobility “most of all on the battlefield. Swift and agile movement, rapidity and assurance of thought are the true essentials.”[73]

There is a clear need to reconsider the deleterious effects of excessive weight on survivability. The weight soldiers carry is unhealthy and unsustainable. It has operational consequences due to the immediate cognitive and physical performance degradation. It inhibits proper respiration, power, endurance, and mobility. The long-term consequences limit recruitment and shorten careers. Soldiers have only become more heavily burdened while warfare becomes more technological. Thinking about ways to improve survivability beyond traditional armor placed on the body will be necessary to protect soldiers from musculoskeletal injury and improve battlefield performance. There are steps the Army could take in the near term, however, to change its equipment, doctrine, and policies to reduce the soldier’s load.

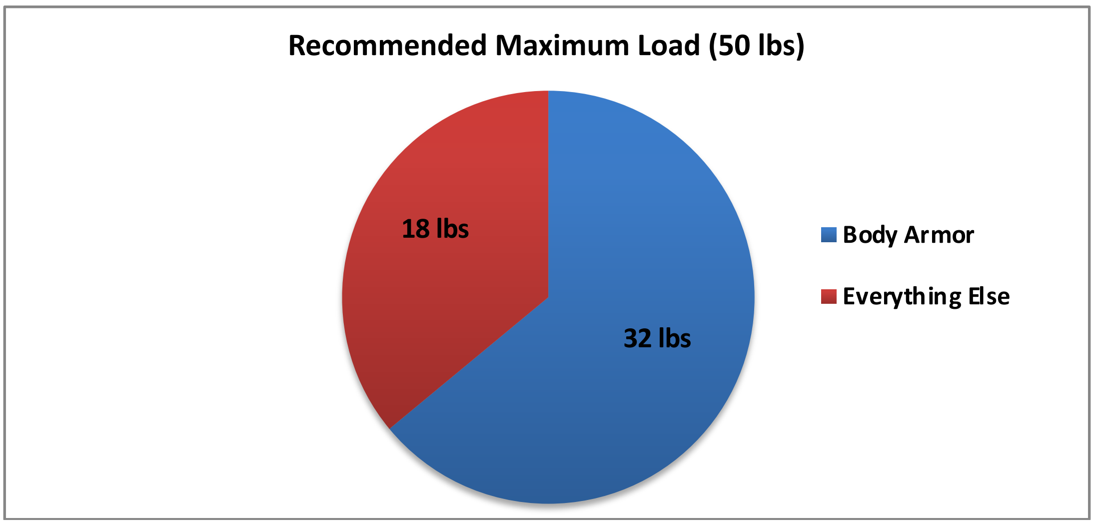
Optimizing Soldier Load and Performance

Army and Marine Corps doctrine acknowledges that carrying excess weight limits combat effectiveness. One problem in reducing weight has been that studies frequently tie load to slower soldier movement, which is intuitive, but often do not take the next step to link heavier loads to measures of operational effectiveness, such as marksmanship, maneuver, or exposure to enemy fire. In order to truly optimize soldier load and performance, there must be a concerted effort to understand and advertise the human performance implications of heavy loads. *The Army should undertake an authoritative study to better assess the relationship between load and combat effectiveness, building on existing literature. This study should detail the limitations and risks of excessive load. The results should be socialized throughout the Army to inform leadership decisions about load configurations by mission requirements.*

Military doctrine on weight limits, changed if necessary based on the human performance assessment, should be enforced with the aim to improve soldier combat preparedness by decreasing the weight carried and adjusting to operational requirements. Part of this effort should be examining which supplies soldiers truly need on the battlefield and opportunities for resupply. *The Army should undertake a thorough assessment of necessary supplies and the fidelity of timely resupply, and educate leaders on the importance of minimizing loads.*

This means reducing equipment carried, such as ammunition, to only that which is mission critical and will be reasonably used. In addition, the physical operating environment should dictate weight limits, as difficult terrain, such as mountains, limits the amount of weight soldiers can reasonably carry.[74] Finally, the guidelines should be understood and organizationally enforced on an individual level. For every pound of additional equipment fielded, a pound should be removed.

This is principally a leadership and training issue, but the problem is hard to resolve given the heavy burden of all the equipment that is assumed to be needed today. The historical recommendations to enable the best agility, cognition, and stamina on the battlefield, as well as protect from injury, all approximate 50 pounds. The weight of protective body armor makes adding necessary equipment and still meeting the weight limit essentially impossible, which highlights the importance of minimizing armor weight. Current torso body armor weighs approximately 32 pounds, leaving only 18 pounds for additional equipment. An M4 carbine with optics weighs approximately 7 pounds, empty. A camelback with 100 ounces of water weighs almost 7 pounds. Night vision devices, a hand grenade, and one MRE add 3.5 more pounds.[75] That amounts to 17.5 pounds, and this hypothetical soldier has no ammunition or helmet.



Body armor itself is modular, and in theory allows commanders to tailor the level of protection to operational needs, reducing weight to increase mobility as needed. Anecdotally, however, most commanders do not vary the elements used. The appropriate level of protection depends on a variety of conditions: the enemy threat, terrain, and mission, among other factors. Army doctrine teaches that commanders should take into account the mission, enemy, troops, terrain, and time (METT-T) when planning operations. For example, wearing heavy body armor may not be operationally practical on a long-range multi-day patrol in mountainous terrain, such as in Afghanistan. In practice, the decision of which protective level to wear is usually restricted to senior leaders. On-the-ground commanders are rarely clearly delegated the authority necessary to adjust the level of protection to conditions on the ground, especially at the company level.

Army leaders are justifiably concerned that that if they made a reasonable choice to balance the level of protection against the tradeoff in additional weight and mobility and a soldier was injured or killed as a result, their decision would be second-guessed by DoD superiors and Congressional leadership. A recent RAND report on lightening body armor noted, “leaders are understandably reluctant to make the decision to scale down threat requirements, lest they be blamed for a soldier death or injury due to projectile-armor overmatch.” The political consequences of a lethal engagement while soldiers are not wearing available armor are high, and it is more politically expedient to simply have soldiers carry heavier armor.

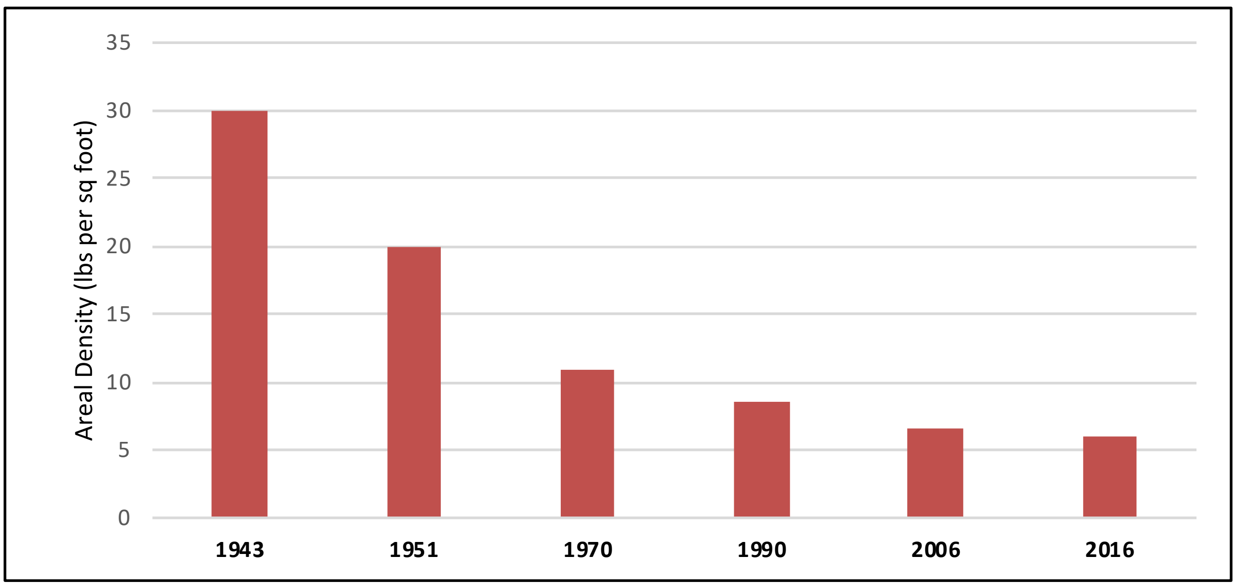
This unfortunate situation harms soldiers in the long run. An overly risk-averse approach that does not allow commanders to adjust the protection level based on specific conditions on the ground may hamper soldier mobility. U.S. soldiers who are overmatched by enemy maneuver are at risk of making contact on the enemy's terms, a dangerous situation that harms overall soldier survivability.

This is not a technical or material problem but rather is primarily a cultural and policy problem. Commanders do not have the clearly delegated authority and backing from superiors, including DoD civilian and Congressional leadership, to modify the level of protection to specific METT-T conditions. *The Army should clearly delegate authority to company-level commanders to modify the level of protection as needed, based on the specific threat and mission.*

Optimizing Body Armor Design to Decrease Weight

Near-term prospects for technological improvements that would fundamentally change the weight-mobility tradeoff are slim. Despite rapid gains throughout the mid-20th century in body armor, progress in better materials has been incremental for the past several decades. From the Persian Gulf War to the Afghanistan War, for example, armor areal density decreased by 24 percent, or roughly only a 2.4 percent improvement per year.[76] Material improvements that have occurred since 2001 have been largely invested in better protection, rather than reduced weight. As a result, body armor weight has actually increased significantly over the past 15 years.

Material Improvements in Armor



Armor areal density (pounds per square foot) is shown for a constant level of protection over time. Improvements in body armor materials resulted in dramatic weight reductions throughout the latter half of the 20th century, but only incremental gains in recent years. Any future significant reductions in body armor weight are likely to come from areas other than material improvements. (Source: Based on data from James Q. Zheng, PPE Weight Reduction Review, August 2016.)

Nevertheless, even given these limitations in materials, there are a number of steps the Army could take in the near term to reduce body armor weight and improve overall soldier survivability without requiring fundamentally new material advances.

Today's body armor systems are likely over-designed in a number of areas, adding unnecessary weight. There may be opportunities to reduce weight without reducing soldier survivability. Legacy Army requirements for system design and construction may make hard armor plates over-engineered.[77] A 2017 Government Accountability Office report stated that according to DoD officials:

> [P]lates may be over-designed and heavier than necessary, based on actual operational threats and [personal protective equipment] performance data collected in Iraq and Afghanistan. According to research officials, updates would allow for weight reductions without increasing the ballistic risk to personnel.[78]

According to the report, researchers may develop new reduced-weight hard armor plates in fiscal year 2019, pending approval from Army senior leaders.[79]

Additionally, by optimizing requirements to the individual soldier, the Army could potentially reduce the weight of current body armor systems, even with current materials. Current body armor comes in a range of sizes (XS, S, M, L, XL, etc.) and, recently, in female-specific body armor to conform to different body types of male and female soldiers. Soldiers' body shapes and sizes vary to a much larger degree than is captured with the currently available sizes, however. Tailored body armor that was specifically designed to fit individual soldiers could significantly improve area coverage and potentially reduce weight. Tailored body armor would eliminate unnecessary gaps where vulnerable parts of the torso are exposed and eliminate excess body armor that is too long or too wide for a soldier's specific body type. Tailored body armor would also reduce unnecessary bulk and increase soldier mobility and responsiveness in dynamic engagements.[80]

Tailored body armor would require a different model for manufacturing and stockpiling body armor. Depending on how uniquely body armor is tailored to each individual soldier, it may need to be manufactured based on the measurements of that soldier as he or she enters the force. Individually tailored body armor options are available for law enforcement, for example. While tailored armor would require some additional cost, the feasibility of adopting this approach at scale would depend heavily on the manufacturing model used. *The Army should conduct an assessment of the feasibility of tailored body armor and potential advantages in reduced weight, increased area coverage, and improved mobility. This assessment should include an evaluation of manufacturing methods to reduce the cost of adopting individually tailored solutions at scale.*

NOTES

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