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ORIGINAL RESEARCH OPEN ACCESS

PHYSIOLOGICAL CONSIDERATIONS FOR MODERN MILITARY RIFLE CARRIAGE

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ABSTRACT

Understanding the physiological demands on Soldiers when carrying various weapon systems is critical for safe and successful training, mission planning, and real world operations. This report introduces foundational characteristics of both currently used and Next Generation Squad Weapon (NGSW) systems. Research gaps regarding rifle carriage are identified in order to enable future analysis on the effects of orientation, modifications, and operational stressors on physiological costs. The six authorized carrying positions for rifles vary based on tactical as well as physiological advantages and disadvantages. Modern weapon standard loads vary based on mission type, purpose, and intent. Published literature specifically assessing the physiological costs of rifle carriage is limited and few researchers have explored the specific costs of rifle carriage or the effects of different carrying positions, postures, and effort requirements. Relevant military physiology studies have generally incorporated a weapon system when testing one or more clothing and individual equipment ensembles to simulate the demands imposed on the dismounted Warfighter. Unfortunately, the physiological impact of the weapon itself cannot be isolated without an unarmed control comparison. There is a lack of research exploring the metabolic cost of different rifle carrying positions, including varying types of weapon systems, and the effects that each weapon system and carrying position may impose on the Soldier. Overall, further investigation into the physiological effects of carrying modern weapon systems in various positions during training and operations is needed.

Keywords: lethality, metabolism, military physiology

INTRODUCTION

Soldiers perform physically demanding tasks with a wide range of different types of equipment for varied periods of time (1). In contrast to athletes and civilian jobs, these tasks can be extended for protracted and unpredictable durations and often lack an ability to safely stop (e.g., no on demand 'breaks', a constant implication of 'life or death' reality) (1). Many researchers have studied the specific metabolic demands on Soldiers while performing physically demanding tasks (2-9). However, the additional metabolic cost associated with carrying individually assigned rifles is not well defined (10). There is a need to study the physiological and physical impacts on Soldier performance during training or operations, specifically isolating the weapon system's impact. Determining the physiological impact of the modern Warfighter with the range of their potential carried loads, (e.g., weapon system, packs, carried equipment) is essential to ensure safe and effective training and provide crucial insights into mission planning for real-world operations. These quantitative insights will ultimately enable optimized training and real-world responses.

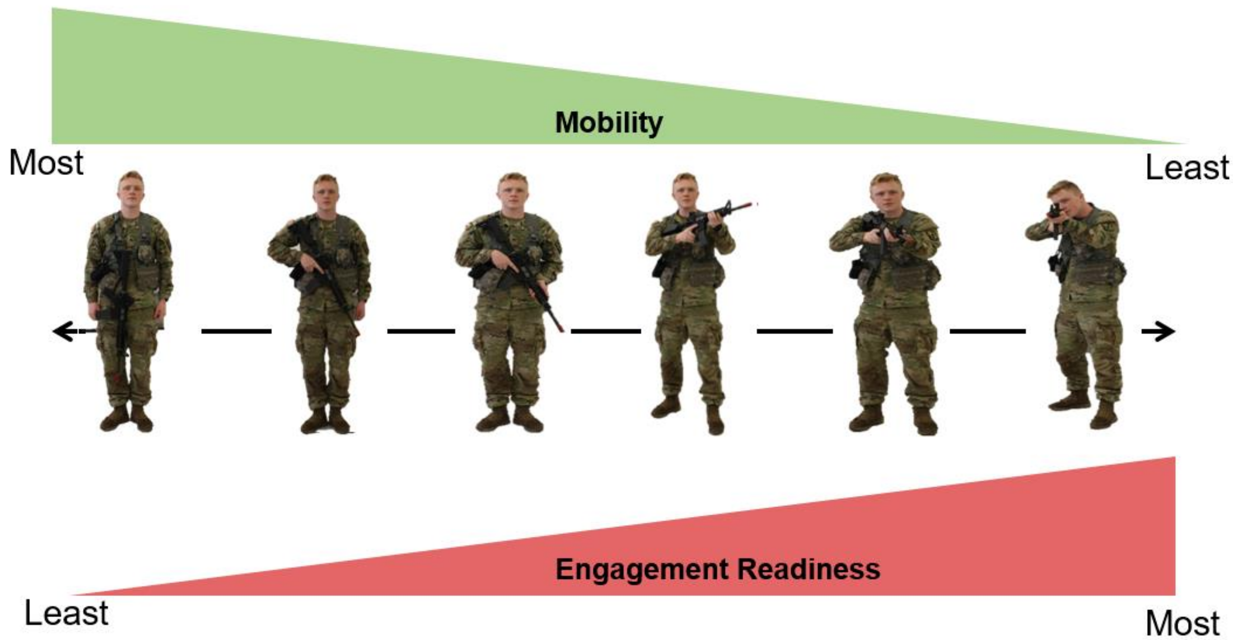
Weapon systems are critical for most military training activities such as patrolling and platoon operations. Individual weapons are particularly vital during dismounted missions and training. As weapon use and carriage are not standardized during field operations, an important consideration is the effect of rifle carriage on metabolic demands. Physiological costs directly impact Soldier performance (3) and ultimately performance of mission objectives. There is a variety of research on the metabolic or physiological effects of backpack loading, body armor, and different types of gear (4, 11, 12). However, none of this research specifically isolates the effects of carrying a rifle.

The goal of this report is to introduce foundational characteristics of rifle carriage. Herein, we will describe the weapon systems most used by modern US Armed Forces in order to illustrate the range of weapon systems that Soldiers are currently using during training and operations. In addition, our report summarizes weapon systems scheduled for introduction as part of the Next Generation Squad Weapons (NGSW) program, the US Army's initiative to replace existing rifle and automatic rifle systems. This report reviews published research on physiological costs of rifle carriage and other hand-carried systems/loads. Additionally, this report helps to identify research gaps related to rifle carriage to enable further analysis and to provide a basis for designing studies to properly assess the demand of carrying a weapon system in various orientations on the Warfighter.

Key Aspects of Rifle Carriage

In Training Circular (TC) 3-22.9 Rifle and Carbine (13), six different authorized rifle carriage positions for shoulder fired weapon systems are described and demonstrated. Table 1 displays the six carrying positions within the Training Circular: 1) hang, 2) safe hang, 3) collapsed low-ready, 4) low ready, 5) high ready, and 6) ready-up. Each carrying position has identified tactical or mobility advantage(s) and disadvantage(s) in displayed in Figure 1.

Figure 1. Inverse relationship between mobility and engagement readiness for authorized rifle carriage positions.



Mobility is defined within FM 3-90-1 as "a quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission" (14). While this definition does not focus on the individual; for the purpose of this report, an individual is considered. The mobility for an individual is defined here as one's capability to move from place to place and have the flexibility to perform their required tasks in order to complete the mission. Mobility is critical as it can dictate the pace of battle and Soldier's safety, and therefore impacting mission readiness (15). There are several physical factors that can play into the mobility allowed by a weapon system such as its dimensions and mass length. There is generally an inverse relationship between the inherent mobility that a Soldier is 'allowed' based on the authorized carrying position and their engagement readiness (Figure 1). Additionally, this inverse relationship intuitively exists between mobility and metabolic demands. The metabolic demands of each position shown in Table 1 can be estimated using physiological and biomechanical principles. For example, holding the rifle versus having the rifle slung would theoretically increase the metabolic demand due to muscle activation and forces against gravity (16). Carrying a handheld object further away from the body's center of mass requires greater activation of upper body musculature for stabilization (17). Increased reliance on these smaller muscle groups induces fatigue faster due to higher recruitment of high-threshold motor units and fast twitch muscle fibers, which are less fatigue resistant than postural or locomotor musculature (16). Furthermore, carrying positions such as the collapsed low ready have a greater moment arm than other positions (e.g. *safe hang*) therefore leading to greater muscle activation needed to stabilize the rifle. We would expect that the *hang* position has the lowest metabolic demand as the weight is distributed to the shoulders and is kept close to the body (16). The *safe hang* would have an increase in metabolic demand from the increased from the supporting arm with slight

Table 1. Rifle carrying positions reviewed in Training Circular (TC) 3-22.9 (13).

Carrying Position	Images	Advantages [+] and Disadvantages [−]
Hang		[+] Provides maximum mobility and freedom of movement [+] Use of hands [−] Least accessible position to weapon [−] Least control of weapon [−] Least readiness for engagement
Safe hang		[+] Allows most mobility while maintaining positive control [−] Limited ability to use hands
Collapsed low ready		[+] Allows some mobility while maintaining positive control [−] Limited ability to use hands
Low ready		[+] Increased readiness for engagement [−] User has reduced awareness behind and laterally [−] Limited ability to use hands
High ready		[+] Increased readiness for engagement [−] User has reduced awareness behind and laterally [−] Limited ability to use hands [−] Takes longer to engage than low ready
Ready-up		[+] Highest level of readiness for engagement [−] User has reduced awareness behind and laterally [−] Limited ability to use hands

lift from the sling. The *collapsed low ready* may have a further increase in metabolic demand as the weapon system is supported by both arms with a slight lift from the slight. The *low, high ready,* and *ready-up* all impose an increase in physiological stress from both supporting arms holding the weapon system against gravity to support the front of the weapon weight. Still, there is no one solution fits all on how a Soldier may carry a weapon system. The mission, terrain, and individual will determine the position that is appropriate for the situation. For example, the high ready may be more advantageous than the low ready in an urban environment or while moving quickly, by decreasing the amount of time needed to drop to the prone position and engage a target.

Modern Weapon Systems

Table 2 shows five different weapon systems currently used in the US Army with varying dimensions, mass, and ammunition types. The weapon systems mentioned in Table 2 all have standardized mounts that allow for the addition of a range of different attachments (e.g., scopes, sights, accessories) (13, 19, 20). Standard loads within infantry and dismounted forces vary by mission type, purpose, and intent. For the purpose of this report, load/carry configurations identified are basic to most infantry dismounted elements and considered equipment common to all (21). Amongst the dismounted infantry, various duty positions dictate a basic load and operate under basic premise of: not all weapon systems at the platoon level are held and maneuvered like the current issue M4 rifle or other single user type weapon systems (12, 22). Note that weapon systems such as the M320 grenade launcher and AT4 shoulder-launched munition are not individual weapons. The M320 can be attached to the M4 carbine or carried along with another individual weapon. While the AT4 is typically carried along side another weapon, tucked underneath the flap of the user's rucksack until it is utilized. These carry restrictions are primarily due to weapon type and purpose within the platoon. For example, the M240 is typically carried with a supporting sling and is rarely fired from a standing position while looking down the sights (19). Additionally, crew served weapon systems, such as the M240, split load carry responsibilities amongst a "gun team" so the discussion of individual load concerns are restricted to the individual carrying the main weapon system. These weapon systems are over 10 kilograms making it difficult to control movement with the weapon system while standing and looking down the sights; therefore, these weapon systems are typically fired in the prone position (19). These factors should be considered when evaluating the metabolic cost of carrying an individually assigned weapon system. Ultimately, the cost will vary based on the weapon system and the carrying position at which the weapon system can and will be held.

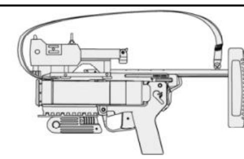
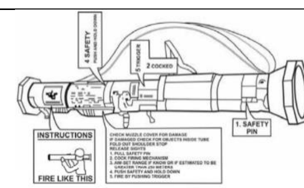
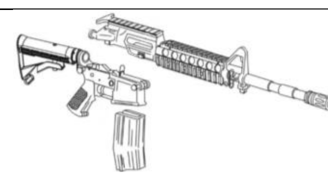
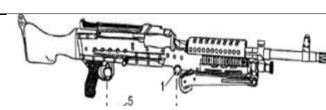
Next Generation Squad Weapon (NGSW) Systems

The US Army initiated the Next Generation Squad Weapon (NGSW) program to equip modern and future dismounted Soldiers with more accurate, lethal, and longer range weapon systems (25). This effort was supported by a study conducted by the Small Arms Ammunition Configuration in 2017 that found different caliber weapon systems were needed to defeat armored threats (26). Key deliverables of the NGSW program include a rifle (NGSW-R) and automatic rifle (NGSW-AR) to replace the M4 carbine and the M249 SAW, which are two of the most common weapon systems used during small unit tactics (20). The NGSW systems rely on 6.8 mm rounds for ammunition instead of the traditional 5.56 rounds in order to increase range, accuracy, and lethality (25-27). The

NGSW program also included the development of a new fire control system that improves firing accuracy with a ballistic calculator that takes the environment and other variables into consideration (25, 28).

On Tuesday 19 April 2022, Sig Sauer's NGSW-R and NGSW-AR models were selected as the winners of the NGSW contract award (Table 3) and the decision was released to the public on the following day (28). This decision was based on how effectively each system met weapon system capability requirements as well as extensive Soldier feedback when used through a variety of conditions such as rifle marksmanship, mobility courses, obstacle courses, and night operations. However, the physiological impact of the newly developed weapon systems has yet to be explored. Additionally, important details such as exact combat capabilities and dimension specifications are not approved for public release, limiting efforts to replicate the NGSW or similarly constructed weapon systems in laboratory settings.

Table 2. Current weapons commonly used in the United States Army.

			Length			
Class	**Name**	**Mass (kg)**	**Total (cm)**	**Barrel (cm)**	**Ammo (mm)**	**Image**
Grenade Launcher (24)	M320	3.2	50	21.5	40	
Shoulder-launched Munition (25)	AT4	6.8	101.6	N/A	84	
Rifle (15)	M4	3.40	83.82	36.8	5.56	
SAW (21)	M249	7.44	103.81	46.5	5.56	
Light Machine Gun (20,21)	M240	12.52	124.46	63.0	7.62	

Note: Ammo, ammunition type; Barrel, length of barrel; SAW, Squad Automatic Weapon; Total, length with buttstock fully extended; Weight, minimal weight of weapon system.

Table 3. Next Generation Squad Weapon Automatic Rifle (NGSW-AR) and Rifle (NGSW-R) systems (26, 27).

Class	Name	Image	Length (cm)	Weight (kg)
NGSW-AR	XM250		106.3	6.58
NGSW-R	XM5		91.4	4.45

Note: Weight, minimal weight of weapon system.

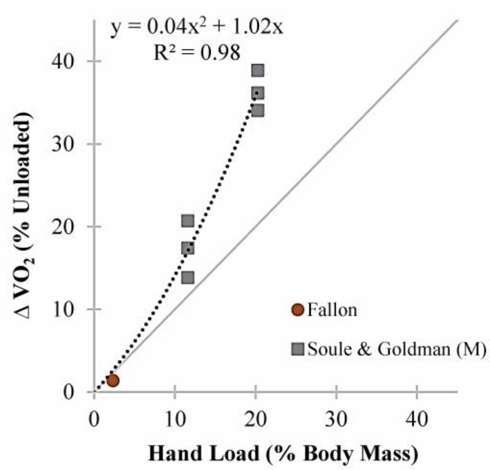
Physiological Costs of Rifle Carriage

Research on the physiological costs of military load carriage dates back over 100 years (29). Commonly examined outcomes include vital signs (body temperature, heart rate, respiration rate) (30, 31) and metabolic measurements from respiratory gases (oxygen uptake, carbon dioxide production, and energy expenditure) (8, 32, 33). While physiological research into specific aspects of military rifle carriage is scarce; key findings from related studies help illuminate a roadmap for future investigations.

Carrying loads by hand is far less metabolically efficient than most other conventional means (34-37) (Figure 2). Compared to rucksack or vest-borne loads, handheld weights are distal from the body's center of mass and greater recruit hand/forearm musculature. Interestingly, loads carried along the center of mass of the arms seem to have similar metabolic effects as loads borne on the torso when walking provided that arm swing is not restricted (38).

Military physiology studies often incorporate a weapon system when testing one or more clothing and individual equipment ensembles to simulate the demands imposed on the dismounted Warfighter (39-41). This includes contrasting varying levels of personal protective equipment (PPE) or Soldier load echelons (e.g., fighting, approach, and sustainment loads) (30, 40). While this approach addresses these studies' original aims, the physiological impact of the weapon itself cannot be isolated without an unarmed control comparison. How the Warfighter responds to the same scenario with a modified or alternate weapon system is therefore difficult to discern. Researchers must directly compare physiological responses between armed and unarmed dismounted warfighters to address this persisting gap in the literature.

Figure 2. Increased oxygen uptake (VO_2) requirements for walking with handheld loads from previous studies (35, 38).



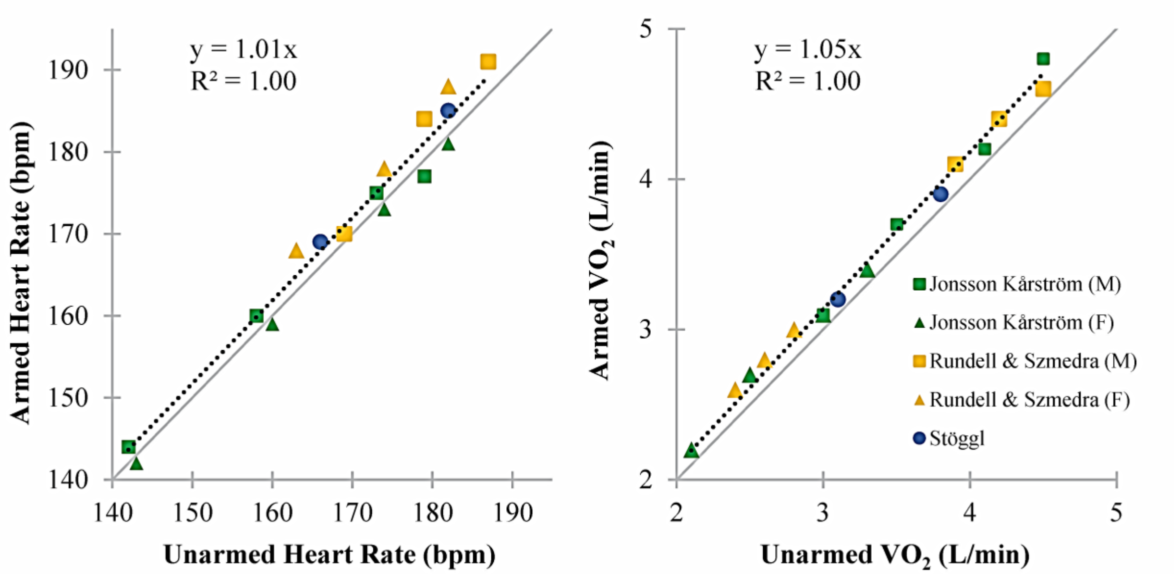
Biomechanical studies have compared ground reaction forces as well as joint kinetics and kinematics between armed and unarmed conditions, albeit without concurrent measurements of physiological strain (42, 43). Holding a rifle reduces arm swing (43), a key mechanism for maintaining lateral balance and reducing the metabolic costs of locomotion (44, 45), thereby decreasing exercise economy and augmenting energetic demands. Therefore, rifle carriage may cause additional physiological strain through decreased mobility, increasing overall metabolic demand to carry out a given task compared to the unarmed Soldier.

Most recent physiological investigations that included unarmed comparisons were biathlon studies involving simulated skiing with the rifle slung across the back (46-49). These studies found that the biathlon rifle, which weighs from 3.5 to 4.0 kg, slightly increases heart rate (~ 1%) and oxygen uptake (~ 5%) during skiing at various intensities (Figure 3). Although the mode of transport and rifle position differ from typical dismounted warfighter tasks, these measured physiological responses provide insight into the lower limits of what would be expected for militarily relevant exercises.

Future Research Areas

There is a lack of published information regarding the isolated metabolic demands of rifle carriage in a military context. Examples of the available types of research explored in this report include biathlete and hand carriage studies that can be used as a starting point. However, neither type of literature directly address the metabolic cost of rifle carriage of military personnel during an operation where the weapon will be carried in several different carrying positions. These studies can also be used to justify that there is a need for further research exploring the metabolic cost of different rifle carrying positions, including varying types of weapon systems, and the effects that each weapon system and carrying position may impose on the Soldier.

Figure 3. Physiological costs of rifle carriage in biathletes during simulated skiing with the rifle slung across the back (47-49).



Once the physiological effects of weapon systems are more thoroughly investigated, additional research into the effects of rifle carriage within varying types of environments and operations can be explored. The way in which the environment affects a Soldier is essential to mission planning and the science of tactics (1, 14). This includes mission variables such as the terrain or the weather. How a weapon system adds to combat stress within different environments should be further explored in order to properly account for and prepare personnel during operations.

Another aspect of mission planning requires assessing the operating levels above and below (i.e., macro and micro level planning) the considered unit (squad, platoon, battalion, etc.) (1). If the mission is for a squad sized element, they are not 'operating within a vacuum'. The squad is working with a platoon, is a part of a company, and so on. Mission planning must take this into account in order to have accountability for their element and the elements around them. This can affect the types of weapon systems that the element can have available, contributing to the combat and physiological stress that a Soldier will experience during an operation. In order to assess the bigger picture during the operation it is important to be able to understand what happens at the individual level to efficiently plan for a larger element (e.g., platoon, company, battalion).

CONCLUSIONS

Rifle carriage encompasses multiple positions in which a weapon system can be carried, with associated advantages, disadvantages, and defined purposes. Multiple different types of weapon systems are used by the US Army with varying sizes and functions. These weapon systems are customizable with add-ons that can cause the weight to vary. The Next Generation Squad Weapon (NGSW) program was created to produce more lethal and accurate variants of the current day weapon systems (e.g., M4 and M249). Published literature specifically assessing the physiological costs of rifle carriage is limited and few researchers have explored the specific costs of rifle carriage or the effects of different carrying positions, postures, and effort requirements. Overall, further investigation into the physiological effects of carrying modern weapon systems in various positions during training and operations is needed.

Declarations

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Disclaimer

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References

1. Headquarters, U.S. Army, The Operations Process. Field Manual Interim 5–0.1, Washington, D.C., 2019.
2. Knapik JJ, Ang P, Meiselman H, Johnson W, Kirk J, Bensel C, et al. Soldier Performance and Strenuous Road Marching: Influence of Load Mass and Load Distribution. *Military Medicine*. 1997;162(1):62-7.
3. Tenan MS, LaFiandra ME, Ortega SV. The Effect of Soldier Marching, Rucksack Load, and Heart Rate on Marksmanship. *Human Factors*. 2017;59(2):259-67.
4. Looney DP, Lavoie EM, Vangala SV, Holden LD, Figueiredo PS, Friedl KE, et al. Modeling the Metabolic Costs of Heavy Military Backpacking. *Medicine & Science in Sports & Exercise*. 2022;54(4):646-654.
5. Doughty EM, Looney DP, Santee WR, Figueiredo PS, Vangala SV, Sanford DP, et al. Assessment of the relationship between rucksack load and standing metabolic rate. United States Army Research Institute of Environmental Medicine (USARIEM), Natick, MA, 01760, Techical Report, T20-10, 2020.
6. Looney DP, Santee WR, Karis AJ, Blanchard LA, Rome MN, Carter AJ, et al. Metabolic Costs of Military Load Carriage over Complex Terrain. *Military Medicine*. 2018;183(9-10):e357-e62.
7. Vine CAJ, Coakley SL, Blacker SD, Doherty J, Hale BJ, Walker EF, et al. Accuracy of Metabolic Cost Predictive Equations During Military Load Carriage. *The Journal of Strength & Conditioning Research*. 2020;36(5):1297-1303.
8. Santee WR, Allison WF, Blanchard LA, Small MG. A proposed model for load carriage on sloped terrain. *Aviation, Space, and Environmental Medicine*. 2001;72(6):562-6.
9. Santee WR, Kraning KK, Matthew WT. Modeling analysis of women litter bearers during heat stress. *Aviation, Space, and Environmental Medicine*. 1999;70(4):340-5.
10. Stephen J. Kennedy RG, John Slauta. The Carrying of Loads within an Infantry Company. Defense Technical Information Center. 1973;73-51-CE.
11. Gregorczyk KN, Hasselquist L, Schiffman JM, Bensel CK, Obusek JP, Gutekunst DJ. Effects of a lower-body exoskeleton device on metabolic cost and gait biomechanics during load carriage. *Ergonomics*. 2010;53(10):1263-75.
12. Ricciardi R, Deuster PA, Talbot LA. Metabolic Demands of Body Armor on Physical Performance in Simulated Conditions. *Military Medicine*. 2008;173(9):817-24.
13. Headquarters, U.S. Army, Rifle and Carbine. Training Circular (TC) 3-22.9, 2016.
14. Headquarters, U.S. Army, Offense and Defense. Field Manual (FM) 3-90-1 2013.
15. National Research Council Commission on Engineering and Technical Systems, Committee to Perform a Technology Assessment Focused on Logicistics Support Requirements for Future Combat Systems. Reducing the Logistics Burden for the Army After Next: Doing More with Less: National Academies Press; 1999. 224.
16. Potvin JR, Fuglevand AJ. A motor unit-based model of muscle fatigue. PLoS Comput Biol. 2017 Jun 2;13(6):e1005581.
17. Uhl TL, Carver TJ, Mattacola CG, Mair SD, Nitz AJ. Shoulder musculature activation during upper extremity weight-

bearing exercise. J Orthop Sports Phys Ther. 2003 Mar;33(3):109-17.

18. Holt KG, Wagenaar RC, LaFiandra ME, Kubo M, Obusek JP. Increased musculoskeletal stiffness during load carriage at increasing walking speeds maintains constant vertical excursion of the body center of mass. *Journal of Biomechanics*. 2003;36(4):465-71.
19. Headquarters, U.S. Army, Crew-Served Machine Guns, 5.56-mm and 7.62-mm. Field Manual (FM) 3-22.68 2003.
20. Headquarters, U.S. Army, Medium Machine Gun. Training Circular (TC) 3-22.240, 2017.
21. Headquarters, U.S. Army, Infantry Platoon and Squad. Army Techniques Publication (ATP) 3-21.8, 2016.
22. Dean C. The modern warrior's combat load, dismounted operations in afghanistan. Natick, MA: US Army Center for Army Lessons Learned; 2004
23. Headquarters, U.S. Army, 40-mm Grenade Launchers. Technical Manual. 2010;3-22.31.
24. Headquarters, U.S. Army, Shoulder-Launched Munitions. Training Manual. 2010;3-23.25.
25. U.S. Army Acquisition Support Center (USAASC). *New Generation Squad Weapons (NGSW)*. 2022. Available from: https://asc.army.mil/web/portfolio-item/fws-cs-2/ [Accessed 22 June 2022].
26. Reinsch SSM. *NGSW Signifies an evolution in Soldier Lethality*. Available from: https://www.army.mil/article/256697/ngsw_signifies_an_evolution_in_soldier_lethality. [Accessed 18 May 2022].
27. Thompson M. *Soldier Lethality team reimagines movement, vision and combat capabilities*. 15 March 2022. Available from: https://armyfuturescommand.com/sl/ [Accessed 25 March 2022].
28. U.S Department of Defense. *Army Officials Brief The Media On The Next Generation Squad Weapons*. 20 April 2022. Available from: https://www.defense.gov/News/Transcripts/Transcript/Article/3006668/army-officials-brief-the-media-on-the-next-generation-squad-weapon/ [Accessed 18 May 2022].
29. Cathcart EP, Boyd-Orr BJBO. The energy expenditure of the infantry recruit in training. HM Stationery Office; 1919.
30. Looney DP, Santee WR, Blanchard LA, Karis AJ, Carter AJ, Potter AW. Cardiorespiratory responses to heavy military load carriage over complex terrain. *Applied Ergonomics*. 2018;73:194-8.
31. Xu X, Karis AJ, Buller MJ, Santee WR. Relationship between core temperature, skin temperature, and heat flux during exercise in heat. *European Journal of Applied Physiology*. 2013;113(9):2381-9.
32. Givoni B, Goldman RF. Predicting metabolic energy cost. *Journal of Applied Physiology*. 1971;30(3):429-33.
33. Pandolf KB, Givoni B, Goldman RF. Predicting energy expenditure with loads while standing or walking very slowly. *Journal of Applied Physiology*. 1977;43(4):577-81.
34. Soule RG, Goldman RF. Energy cost of loads carried on the head, hands, or feet. *Journal of Applied Physiology*. 1969;27(5):687-90.
35. Schertzer E, Riemer R. Metabolic rate of carrying added mass: a function of walking speed, carried mass and mass location. *Applied Ergonomics*. 2014;45(6):1422-32.
36. Campana CT, Costa PB. Effects of walking with hand-held weights on energy expenditure and excess postexercise oxygen consumption. *Journal of Exercise Rehabilitation*. 2017;13(6):641-6.
37. Fallon KM. The Impact of Wearable Weights on the Cardiovascular and

Metabolic Responses to Treadmill Walking. Graduate Theses and Dissertations Master of Arts, Department of Physical Education and Exercise Science), University of South Florida; 2009;1958.

38. Arellano CJ, McReynolds OB, Thomas SA. A low-cost method for carrying loads during human walking. *Journal of Experimental Biology*. 2020;223(23).
39. Potter AW, Santee WR, Mullen SP, Karis AJ, Blanchard LA, Rome MN, et al. Complex Terrain Load Carriage Energy Expenditure Estimation Using GPS Devices. *Medicine & Science in Sports & Exercise*. 2018;50(10):2145-2149.
40. Polcyn AF, Bensel CK, Harman EA, Obusek JP, Pandorf C, Frykman PN. The Effects of Load Weight: A Summary Analysis of Maximal Performance, Physiological, and Biomechanical Results From Four Studies of Load-Carriage Systems. Technical Report. U.S. Army Soldier and Biological Chemical Command Soldier Systems Center, Natick, MA: U. S. Army Research Institute of Environmental Medicine, Division MP; 2002. Report No.: NATICK/TR-02/010.
41. Chatterjee T, Paul S, Pramanik A, Chowdhury B, Pal MS, Majumdar D. Cardio-Respiratory and Metabolic Changes during Continuous Uphill-Downhill Load Carriage Task. *Ergonomics for Rural Development*. In Proceedings of International Conference on Ergonomics, HWWE,2013, 3-10.
42. Birrell SA, Hooper RH, Haslam RA. The effect of military load carriage on ground reaction forces. *Gait & Posture*. 2007;26(4):611-4.
43. Seay JF, Hasselquist L, Bensel CK. Carrying a rifle with both hands affects upper body transverse plane kinematics and pelvis–trunk coordination. *Ergonomics*. 2011;54(2):187-96.
44. Arellano CJ, Kram R. The energetic cost of maintaining lateral balance during human running. *Journal of Applied Physiology*. 2012;112(3):427-34.
45. Arellano CJ, Kram R. The metabolic cost of human running: is swinging the arms worth it? *The Journal of Experimental Biology*. 2014;217(Pt 14):2456-61.
46. Jonsson Kårström M, McGawley K, Laaksonen MS. Physiological Responses to Rifle Carriage During Roller-Skiing in Elite Biathletes. *Frontiers in Physiology*. 2019;10(1519).
47. Rundell KW, Szmedra L. Energy cost of rifle carriage in biathlon skiing. *Medicine & Science in Sports & Exercise*. 1998;30(4):570-6.
48. Stöggl T, Bishop P, Höök M, Willis S, Holmberg HC. Effect of carrying a rifle on physiology and biomechanical responses in biathletes. *Medicine & Science in Sports & Exercise*. 2015;47(3):617-24.
49. Jonsson Kårström M, McGawley K, Laaksonen MS. Effects of Additional Rifle-Carriage Training on Physiological Markers and Roller-Skiing Performance in Well-Trained Biathletes. *Journal of Science in Sport and Exercise*. 2021;3(3):292-302.