Master Thesis Summary

The Dismounted Soldier: A Critical Analysis On The Associated Complications with Load Carriage System Design to Protect And Increase Survivability

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Abstract

The dismounted solider is faced with many challenges in terms of having an effective and efficient means of carrying load. The solider can be expected to carry up to 120lbs extra weight on top of their current body weight. Furthermore, the solider must travel by foot with this additional weight thorough various dangers and alternative terrains for large distances. In addition, mobile warfare requires more supplementary equipment leading to the solider being unable to manage the overload. Despite of the advances in technology, there has been little progress in understanding the associated physiological and biomechanical aspects of heavy load carriage. The current means of load carriage systems has impeded solider mobility and therefore, has led to lower body injury and in some cases death. There has been little progress within the research made in reducing the impact of solder load. The military is now considering its options to reduce the overall weight by redesigning every item that the soldier carries.

Keywords: Dismounted Solider, Load Carriage Injuries, Musculoskeletal Damage, Warfare Mortality , Joint Impact, Physiological Adaptation.

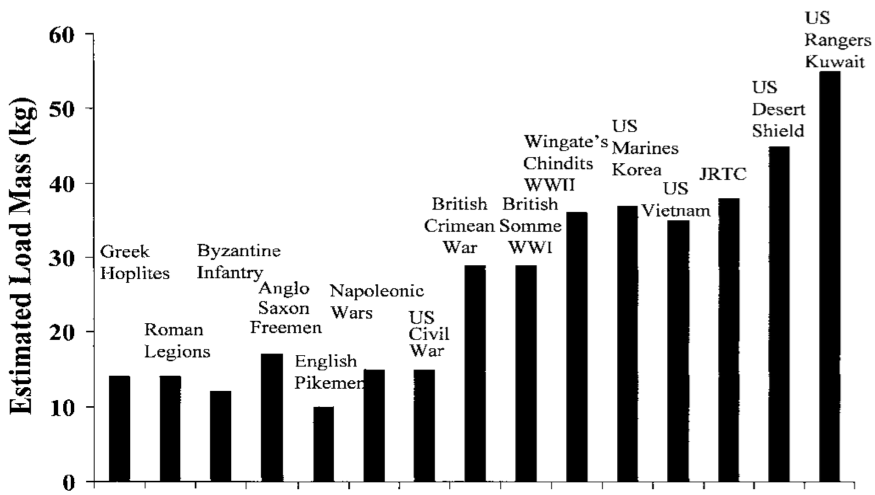
1. Introduction

Throughout recorded history, it appears that the dismounted solider had always needed to devise a means to regularly transported necessary equipment for their survival. Figure 1 illustrates the estimated load mass carried on the March by various infantry units throughout history.

Loads carried by Pre-Musket Soldiers (700 BC-1651AD) until modern conflicts (1950 AD till present) portray persisting inefficiencies on their distribution (Drain et al, 2012;

Orr 2010). There appears to be a reoccurring issue that has persisted for many decades concerning the nexus between the ergonomics of soldier load carriage and necessities required for their mission.

Figure 1
Load Carriage on The March by Various Infantry Throughout History



Source: (Knapnik et al., 2004)

The base load carried by the solider necessitates the transportation of nourishment and sustenance, clothing, combat equipment, protective gear, arms and ammunition (Orr, 2010). It is imperative that the equipment carried is suitable for the mission, to obtain success and survival. The total load carriage will vary based on the report of the threat at hand (Drain, Orr, Attwells & Billing, 2012). In addition, load carriage depends on the equipment needed for mission specific objectives, environmental factors and various terrains (Orr, 2010).

A dismounted soldier's typical load carriage system (LCS) is a back pack and webbing (Birrell, Hooper & Haslam, 2007). The dismounted solider must endure the physical, environmental and psychological demands of transporting various equipment loads on specific locations on their body. The major point being that the dismounted solider must move on foot and transport their military equipment. In accordance to the research, there has been an apparent increase in heavy load carriage for the solider during their operations (Knapnik et al, 2004; Orr, 2010.). As the weight of the load increases so does the physiological costs and biomechanical efforts of carrying that load (Orr et al., 2013). It has been documented that a solider can carry at times up to 60% of their body weight during their mission and this inevitably creates a high risk for musculoskeletal injury (Birrell, Hooper & Haslam, 2007). In the United States, a solider can carry an extra 45kg-62kg during operations (Sealy, 2015). This would translate to a 150 pound solider carrying and extra 100 to 137 pounds on their existing body weight. The important question at hand is how can there be an efficient, effective and practical strategy for the dismounted solider to complete their mission and survive while carrying such loads. There appears to be a lack of research in the biomechanical aspect of effective solider load carriage design.

There has not been significant advancement in reducing soldier load reduction. It appears that the issue may be in part to the thinking of the military commander (Task Force Devil, 2003). The commander is responsible for setting the combat load that is required for the soldiers to carry on the operation. Furthermore, combat load is the essential load that is carried by soldiers (Task Force Devil, 2003). However, the extent of the load on the soldier's body can become problematic to the point where it can impede the mission and their health.

Both female and male soldiers attribute the cause of their injuries primarily to wearing heavy equipment, especially loads of up to 62 lbs extra of their body weight (Drain et al, 2010; Roy et al, 2015). In addition, it should be noted that both 'dry' and 'wet' load (e.g. environmental / climate factors) exist and present different factors in managing the existing mass on the body. Non-combat related injuries endured have led to solider inefficiencies during operations in Afghanistan. In a survey of 593 soldiers deployed for 12 months in Afghanistan, it was revealed that 45% (approximately 267 out of 593) sustained an injury due to tasks requiring the physical expenditure of load carriage: lifting and standing (Roy et al., 2012). The former example implies the seriousness of the problem that nearly half of the soldiers were injured due to the demands of load carriage. The increase risk for carrying excessive loads have created altered battle tactics, reduced army size, caused injuries and resulted in death of the solider(s) (Orr, 2012). Soldier load carriage can be improved by lightening loads, improving equipment, and finding innovative ways to distribute the load on the body.

Despite advancements in technology, the solider load carriage systems have not proven themselves able to help reduce weight in terms of sustainment stores, protective and lethality equipment (Orr, 2010). It is very difficult and sometimes impossible for a dismounted soldier, even one that is in great physical shape, to carrying an increased load carriage for even short periods of time (Mawashi, 2009; 2010). There is an apparent need to develop research on this phenomenon to minimize injury to both female and male soldiers. According to Orr (2010):

> "Where the soldier's protective and lethality equipment and sustainment stress have changed through necessity and technology, the soldiers load has not reduced. Logistical and technological transport aides have changed over the last two millennia, the soldier's load has not reduced. Even where the nature of warfare has changed, from converging phalanxes and trench warfare to today's complex battlefield, the soldiers load has not reduced", p.79.

2. The Main Research Question

The dismounted solider is required to move on foot for continuous and lengthy periods of time through various changing environments and climate. Moreover, they need to perform their tasks with an external load added to their own weight. There appears to be little to no research discussing efficient and effective ways in dispersing load on the dismounted soldier's body in an attempt to increase the likelihood of survival and mission completion. With this in mind, the main research question has been developed as follows:

> "What are the constituents of an applied biomechanical model that would ameliorate solider load carriage systems to be utilized with efficiency, prevent injuries and convert energy to better outcomes and enhanced survivorship?"

The research adopts a mixed methodology in order to be able to isolate the main aspects and influences on dismounted soldier load carriage design and injury prevention, explore the felt experiences of the soldier on a more appropriate design dynamic. The qualitative aspects of the research use Grounded theory as an inductive approach through its development of theory from data collected from the phenomenon (Moustakas, 1994). The present research extracts praxis and principles from responses provided by way of semi-structured interviews of selected dismounted soldiers to arrive at a holistic consensus of ease of load and its functionality.

Keeping in mind that the demonstrated lack of significant research of dismounted solider load carriage and its assumed importance to the individual and team, the present research focuses on examining four main objectives:

4 Main Research Objectives	
1.	To understand how the dismounted solider currently carries load on the body;
2.	To examine how dismounted solider load is acquired, measured and the situations that hinder and enhance its progress;
3.	To compare the findings of the present research to the existing academic literature to determine solutions to the existing problems; and
4.	To generate aload model that can be used across the profession.

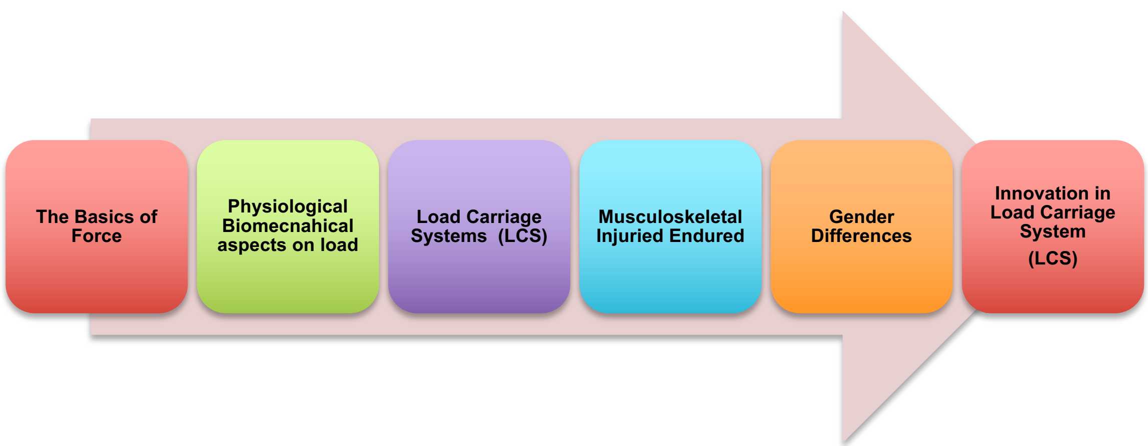
The theoretical framework is based on an integrative literature review approach. The selection of this distinctive form of research assists in generating new knowledge of an effective dismounted solider load carriage. Additionally, it brings forth a more holistic approach to the concept of dismounted solider load carriage as the framework is designed upon various academic disciplines. The theoretical literature review is separated into categories to allow for analysis and integration of the writings in order to formulate the essential determinants on load carriage and the dismounted soldier.

In addition, the review allows for the bridging of historical to modern perspectives on the dismounted solider load carriage design, theory and practices to extract important determinants in the attempt to arrive at better solutions.

3. Literature Review

Load carriage systems (LCS) for the military population have been met with great complexity and lack of clarity in terms of improving outcomes. There is also an apparent lack of research for understanding biomechanical aspects for the dismounted soldier. Thus, an integrative thematic literature review is selected to respond to the main research question. This allows for the generation of different categories and sub-categories experienced with dismounted solider load carriage. The grahic below illustrates the literature review landscape used to determine the importance of reducing and enhancing the biomechanical aspects of load in bettering outcomes for the dismounted soldier.

Integrative Literature Review



Source: Bujold (2018)

Integrative Literature Review		
1.	The Basics of Force	The basic principles of force, weight, mass and acceleration to understand the impact on an object and impact on force during locomotion. This section will aide in highlighting how internal and external influences affect the soldiers' objectives;
2.	Physiological & Biomechanical Aspects	The physiological strain aspects of load carriage;

3.	Load Carriage Systems	The back pack and its variations will be reviewed and evaluated. In addition, a discussion will occur on the solutions, benefits and problems associated with each design;
4.	Musculoskeletal Injuries	Various studies will be reviewed to bring insight on the major parts on the body that are injured on both the female and male solider. This will be pertinent in making improvements to the current load carriage system designs;
5.	Gender differences and Load	Will review what happens biomechanical to the sexes when transporting load;
6.	Innovation in Load Carriage Systems	The technological advances in load systems will be reviewed;
Critique of the Literature		This section will synthesize and integrate the literature to develop an understanding of the integration of the literature and theories thus far. This section will prove to be critical in the answering the main research questions and will set the tone for Chapter Five that is solely based upon synthesis and integration of the research findings.

3.1 Basics of Force

To understand an action on force we must consider four characteristics defining force:

Characteristics Defining Force	
Point of application	For example, attachments to muscle to bones, center of mass of a limb;
Line of application	Force acting anywhere along the line;
Direction of push or pull	The direction of the force. For example, the gravitational force acting downwards on the body;
Magnitude	The quantity of the force.
Source: Brown, 2001, p.242	

The most common force is gravity, which is based on a mutual attraction between two objects. The magnitude of the force of gravity is directly proportional to the mass of each object and inversely proportional to the distance over the negligible attraction between other objects.

3.2 Physiological and Biomechanical Aspects of Load Carriage

Research has been conducted on the physiological strain aspects of load carriage. In the study by Holewign & Meeuwsen (2000), the effects of three different masses (0 kg, 5.4 kg, 10.4kg) was conducted on four male subjects (non-soldiers) and the type of back pack being carried either around the waist or shoulder.

The results of the study revealed that while the participants were standing, there wasn't any impact on oxygen uptake by the type of back pack or mass. A physiological response was shown in heart rate of about 9 beats per minute when just standing with the back pack (Holewijn & Meeuwsen, 2000). However, walking with the mass influenced both the heart rate and oxygen uptake but had no significant impact on the participants tolerance levels (Holewijn & Meeuwsen, 2000).

Another physiological response was noted from the same study based on muscular strain. Increasing the load added an extra force on the trapezius muscle and that continued to double with the doubling of the load. The custom-built pack transferred the load to the hip due to a flexible frame leaving a constant load only on the shoulder for stabilization (Holewijn & Meeuwsen, 2000). Skin pressure was also evaluated in this study. The results showed that the pressure on the skin produced from the shoulder straps was less than 10kPa (75mmhg) (Holewijn & Meeuwsen, 2000). It is suggested that 14KPa(105mmg) can cause skin irritation, inflammation of the dermis, edema, within a two (2) hour period (Holewijn & Meeuwsen, 2000). In the custom pack, the frame transferred a considerable amount of mass to the hips and reduced pressure of shoulder straps (Holewijn & Meeuwsen, 2000). The waist belt prevented it from slipping off the hips but necessarily needed to be pulled tight causing compression which in turn may create muscle weaknesses from pressure to superficial nerves (Holewijn & Meeuwsen, 2000).

A separate study by Harman, Han and Frykman (2000) argued that most research on biomechanics places emphasis on gait and there were only a few studies that have specified load carried. Their study focused on the greater effects of backpack weight on gait biomechanics. They noted positive adaptions from the changes in gait by the body as the backpack weight was increased. However, there was an increase in forces and torque to the ankle, knee and hip. This was an inescapable consequence of carrying heavy loads and most likely increases the risk of musculoskeletal injury (Harman, Han & Frykman, 2000).

3.3 Load Carriage Systems

Research by Winsmann and Goldman (1976) measured the cost of work by comparing tow load carriage systems on a treadmill. They conclude that as long as weight is properly distributed over the body, weight is the most important factor in load carriage rather than the specific load carriage design system. Conversely, Legg and Mahanty (1984) tested five different modes of load carriage and concluded that there were no differences in the respiratory and metabolic costs of the different modes of load carriage, but there may be a single best way to carry 35% body weight (BW) load close to the trunk.

Notably, there appears to be a reoccurring debate on where the ideal place to distribute load versus weight lies, citing the issue as the problem of load carriage and not the system itself. The research indicates physical mobility limitations, strain and/or musculoskeletal injuries.

3.4 Musculoskeletal Injuries Endured

Research by Sealy (2015) states that the incidence of disability has increased six-fold mainly driven by musculoskeletal injuries (”MSI”). To reiterate, non-combat injuries and illnesses have had a significant impact on missions (Sanders et al, 2005). MSI is the most common reason for seeking ambulatory care in deployed environments (Roy et al, 2015). Moreover, MSI accounts for over twice as many evacuations as combat injuries 19.5% to 35% (Roy et al, 2015). Female (up to 57%) service member training has higher rates injury than men (up to 46%) (Roy et al, 2015). MSI accounts for 49% to 64% of the incidences for infantry, combat engineers, artillery and special forces (Roy et al, 2015). Females suffer more upper extremity injuries, whereas men suffer major back injuries. Load refers to the equipment worn by the soldier. The average load carried was 29 lbs and these injuries were reduced when carrying 12 lbs (Roy et al., 2015). Some of the load was greater than 30 lbs. What is important to note from this study is that loads greater than 30lbs can create MSI (Roy et al., 2015). Greater than 50lbs is the leading cause of non-fatal injuries (Roy et al, 2015).

The research of Drain et al. (2012) and Attwells (2008) found that the main biomechanical effects from heavy load was an increased in the range of motion (ROM) of the femur and knee in the lower limbs. The impact of this led to an increase in forward lean creating a counterbalance as the head and truck must perform this task as the load increased, which impacted muscle recruitment added stain and injury as the muscular force had to increase to carry the load exacerbating the potential for injury. The period of load duration was an operational activity of about 2 hours (Drain et al., 2012).

3.5 Gender Differences

The female solider is now being exposed to heavy military load carriage and it is necessary to compare the injuries with her male counterparts (Orr & Pope, 2016). Female soldiers have injuries similar to male’s lower back pain with carrying load but a greater incidence of related foot injuries. The research concluded that the smaller female stature may predispose them to a higher risk of injuries while carrying loads (Orr & Pope, 2016). The results were indicative of this thought but, in some cases, women had twice the risk of injury. It is concerning that as women move into combat roles carrying heavier loads this will need to be resolved to decrease injuries (Orr & Pope, 2016). It is important to note that the similar shorter stature male soldiers and conversely, a tall statured woman may experience lower load carriage injuries than men (Orr & Pope, 2016).

During basic training, it was found that more women have a higher incidence of musculoskeletal injuries. Therefore, a simple study was conducted using healthy women to carry 10kg load on the back, around the waist and across one shoulder (Ling et al., 2000). The intent was to examine gait patterns and shoulder muscle strength on their gait with the different load configurations (Ling et al., 2000). The research showed that every load configuration had a different impact on trunk and shoulder angles and measured the most rigid and flexed trunk when carrying load on the back (Ling et al., 2000).

Moreover, carrying a heavy weight load across the waist caused less deviation from normal gait pattern for women (Ling et al., 2000). Woman with stronger shoulder muscles demonstrated less trunk and shoulder deviations when walking with a heavy load on the back (Ling et al., 2000). The worst configuration was across the shoulder because of less mobility for the shoulder. Moreover, the across one shoulder set-up lead to discomfort in the neck, shoulder and back. Shoulder girdle strength positively correlated with a woman's trunk and shoulder movement's while wearing heavy loads around the waist or back (Ling et al. 2000).

3.6 Innovation in Load Carriage System

The works of Gregorczyk et al., (2010) examined the biomechanical effects of gait and metabolic costs during load carriage, lower body prototype exoskeleton ("EXO") on static limits on stability and postural sway. This was one of the first studies to examine energy expenditure and gait biomechanics using an EXO designed for load carriage assistance. There were three different weights: 20kg fighting load, 40kg approach march and 55 kg emergency approach march. The soldiers had 4 to 6 hours of acclimation to the EXO prototype. The results showed that body leaning to the right and left was significantly less than the test group carrying only 15kg. The maximal range of motion was significantly reduced when the EXO was used (Gregorczyk et al., 2010).

The issues with the design was that the EXO was not designed to offload 100% of the vertical load component or decrease the load vertically. The EXO raised metabolic costs significantly and resulted in differences in a number of biomechanical measures compared with carrying the same loads without the device (Gregorczyk et al., 2010). One issue was that the task reworking VO2 of more than 28.6ml/kg of body mass per minute are classified as extremely heavy effort, which cannot be sustained for durations greater than 20 min (Gregorczyk et al., 2010).

Other EXO studies were also done to mitigate the fatiguing effects reported with prolonged load carriage during marches. During an 8 km march on post march obstacle course and repetitive box lift performance the effects of wearing an EXO was that the mass and distribution on the body and design elements altered the users gait patterns. Interestingly, there is need for the user to be able to control the inertia of the device and load attached to it. The majority of studies have focused on infantry soldiers support in the gravitational direction when walking on flat terrain. This type of thinking may be in error as slopped and rough terrain are the reality of the infantry soldier's world.

3.7 Research Gap and Critique

There appears to be four major influences on load carry, see below. Each dimension and their influence are highlighted.

4 Influences on Load Carry	
Human-Personal Characteristics	The individuals, size, stature, bone structure, height and weight;
Mission-Task Characteristics	Total external load, distribution of load, load carriage system, design, movement, speed, march duration, work to rest ratio.
Environment	Altitude, terrain, climate. Whether the soldier is under fire or not;
Biometrical Design (Lack of)	The area where more innovation and solutions are required and is presently lacking. There has not been an advance in the design of LCS to actually reduce load carried. The current designs bring insight into physiological responses and biomechanical aspects but it is not enough to help the overcome their challenge. This section is highlighted as it is deemed as one of the crucial dimensions to correct requiring significant improvements.

The majority of the research has focused initially on the physiological responses to various loads mounted on the back, or front and back. Variables such as age, gender, stature come into play for load carried. More so, the physiological response studied proved to be essential in understanding the impact of increasing load on heart rates, skin pressure, forward and/or backward trunk lean (postural changes) and arm swing frequency. These studies similarly deduced that trunk lean, hip rotation / flexion, knee range of motion and ankle where reduced or modified with incremental effects as load increased. Also, these studies deduced that increasing weight led to acute, chronic musculoskeletal injuries in both sexes. The former means an actual reduction of number of infantry soldiers deployed on operation with a resulting impediment to the overall mission with the possibility of higher risks and the possibility of increased solider death.

4. Methodology

The methodology employed in the present research is qualitative by way of phenomenological research. The Qualitative research approach allows for developing a deeper understanding of existing problems within the phenomenon and allows for converging new ideas with old (Trochim, 2006). For example, with respect to the beliefs and roles of the dismounted soldier in ambiguous, and life-threatening environments it would prove to be difficult to develop a quantitative methodology that would elaborate upon the issues experienced by the dismounted solider in war zones.

4.1 Appropriateness of Method

Phenomenological methodology is considered the most appropriate in order to capture subtle meanings and personally held experiences in order to avoid imposing external thought complexes on the participants (Moustakas, 1994). Furthermore, a Grounded Theory approach is an appropriate method for developing theory about the phenomena of interest. In this case, Grounded Theory is used to research the beliefs and experiences of dismounted soldiers. Grounded Theory allows for exploratory linkages to be developed between the theoretical concepts and the data collected (Trochim, 2006). Qualitative research allows for analysis of how people think and it generates in-depth information about specific topics (Trochim, 2006). Selecting a qualitative methodology to research the dismounted soldier allows for the description of the challenges, functions and roles of the dismounted solider through their own colloquial speech and in eminent detail.

4.2 Research Design

The research design is rooted within the 'Grounded Theory' approach in order to be able to isolate the main aspects and influences on soldier load carriage systems. Grounded theory unravels the elements of experience (1994, p. 4). Grounded theory is an inductive approach through its development of theory from data collected from the phenomenon (Moustakas, 1994). The research methodology is split into three sections being:

Research Methodology Sections - Steps	
Introductory and Setup Appointment Email	This was the initial recruitment method for introducing the research topic and the researcher credentials. Secondly, to introduce the school and its credentials as well as the consent forms;
Telephone Interviews	The use of a semi-structured questionnaires to uncover the experiences and beliefs held by dismounted soldiers with respect to load carry;
Follow-Up Interviews	Allowed for further elaboration and clarification of the Participants responses. A semi-structured interview is carried out for clarification on the received survey responses. In addition, approval and corroboration of the transcribed data taken from the original conversations that were held was reviewed and ontained.

5. Data Presentation

Responses Were Collected in Two Sections	
1. Participant Profile Respondents were coded within their respective demographic areas (LCS1 to 5):	Coded Research Name: LCS # ___ Gender: Country: Formerly or currently a Solider: Y or N If yes, Unit Type and Rank: Organizational Level: Years of Experience working in Defense/ Military research? Uponwhich area or domain is your research expertise focused?
2. Data Clasifications	13 data classifications influenced or affected load carriage and its current system design.

6. Synthesis and Integration

The present research contacted various Load Carriage Scientist (LCS) throughout North America and Australia. The affiliated agencies produced a total of five LCS within top governmental positions in defense research to provide insight into responding to the main research question. Using telephone interviews, the research was able to collect and generate a set of variables relating to load carriage systems and its constituents and hinderance. Upon comparison of LCS responses to the literature it revealed twelve essential elements.

12 Essential Elements From The Literature	
1.	The need for modularity in load carriage system design;
2.	Variability in human body shape not anthropometric designing needed to accommodate the general population;
3.	The systems are not geared toward helping soldier sustain missions for up to one week;
4.	The systems are too heavy and bulky;
5.	The systems are not dynamically fitted well;
6.	The systems are not statically fitted well;
7.	Areas needed for safety;
8.	Better test methods are needed;
9.	Human performance and cognitive performance testing require;
10.	A holistic approach is needed to bring all technologies together;
11.	The need for more wearable technologies- with integrated SMART technologies;
12.	Need to qualify what the soldier would like to have rather than giving them a generic kit.

6.1 The LCS Views on The Soldier

The investigation on the Load Carriage System and its pending issues have revealed three compelling interests concerning the dismounted soldier.

3 Compelling Interest Concerning The Soldier	
Personality of the Soldier	They only bring what they need: meaning they only carry what they think will be required; In a combat situation, they want to be able to access everything they carry;
Characteristics of the Soldier	Knowledgeable, adaptable, clever, self-aware, managed, dedicated and committed. Often think they need more than is necessary. A person with a certain set of characteristics and traits based on through understanding and sense of the self for developing and serving themselves and others, non-compliance with authority if they can't reach something that is needed;
Regime Influences	Finance, politics and political situation, soldier readiness, soldier type, leader readiness, reciprocation in collaboration and role, more education tools required.

6.2 Influences on the Soldier and Load Carry

There are three outstanding influences on the soldier that are determined by both internal and external factors of control:

Influences on the Soldier & Load Carry	
Government	Funding and investments into public security and safety;
Financial	Lack of private and public investment. Departmental or organizational spending and budgeting;
Technological	Keeping up with the generational differences and the speed of technological advancements. Texting, computers, and other transitional items.

6.3 Collaboration of Soldiers

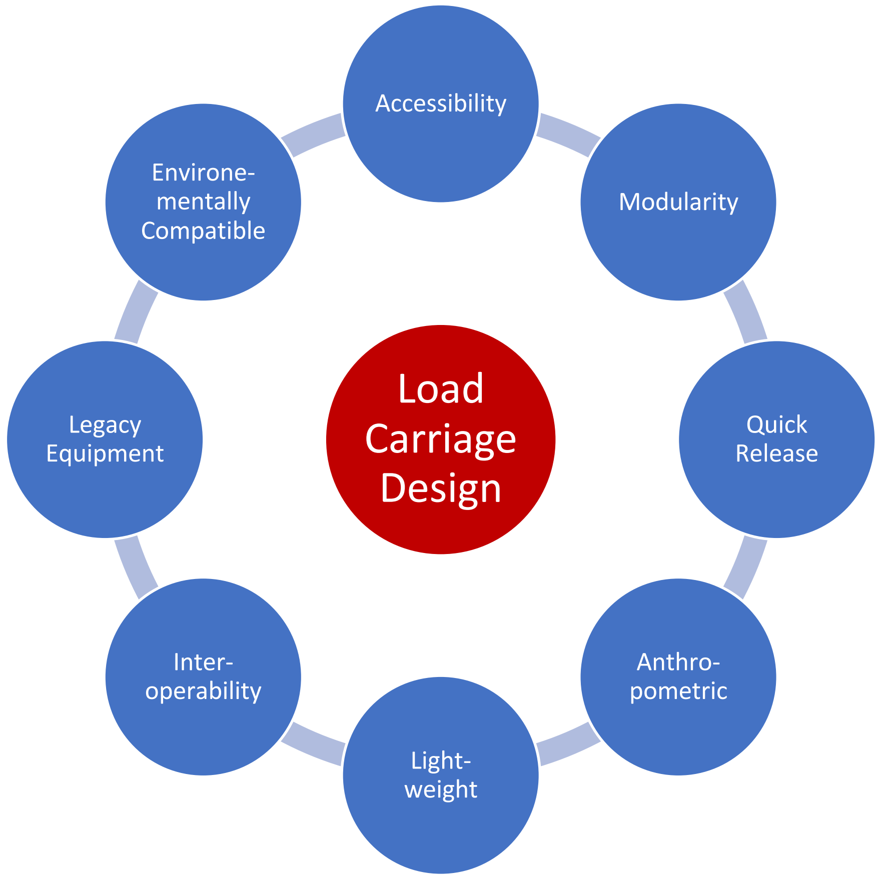
The research reveals how soldiers with different or similar expertise collaborate to get a job completed or achieved. There are three important elements:

Elements of Colaboration In Job Performance	
Role Awareness	Identifying each other's strengths and weaknesses and differences in skill set or expertise. Information is gathered from communication and education and previous educational training;
Communication	Clear communication to build effective strategy and safety for everyone and in order to achieve best results or objectives;
Planning	Complementing each other's strengths and weaknesses. Anticipation of substitutes and substitutions.

6.4 New Framework For The Dismounted Load Carriage System

As synthesized and integrated in the previous sections, a new framework of design for load carriage systems that is not commonly discussed or seen in the seminal literature is presented below.

Framework for Load Carriage System Design



DO's

1. Accessibility
2. Modularity
3. Quick release from the body
4. Anthropometric
5. Lightweight
6. Interoperability
7. Compatible with Legacy Equipment
8. Compatible with the Environment

DON'Ts

1. Forget what was done in the past.
2. Do not think that what worked yesterday will work tomorrow.
3. Not paying attention to what is happening around you.
4. Not speaking directly with end user.
5. Not asking for feedback on personal leadership, thoughts and ideas.

Source: Bujold 2018

7. Conclusion

In conclusion, the dismounted soldier is overloaded. It appears that the future is going to get worst unless there are viable solutions to accommodate the needs of the soldiers and better assist them to meet the mission objectives through the design of better load carriage systems. The presented research represents the critical and salient issues obtained from the investigation that should be the focus of future research.

Bibliography

1. American Society for Surgery of the Hand(ASSH).(2017)*Brachial Plexus Injury*. American Society for Surgery of the Hand. [http://www.assh.org/handcare/hand-arm-injuries/Brachial-Plexus- Injury.

2. Amoroso, P.J., Bell, N.S., Baker, S.P. & Senier, L.(2012). Injury control. In Friedl, K. Santee, W.R (Eds.), Military Quantitative Physiology-problems and concepts in military operational medicine, 339-342.

3. Abdulrahman,S.A.,Rambely,A.S.,& Ahmad,R.R.(2011).A biomechanical model via Kane's equation-solving trunk motion with load carriage. *American Journal of Scientific and Industrial Research*, 2(4), 678-685.
4. Adolph,K.E.(2008).Motor and physical development locomotion. New York University, New York, USA.

5. Attwells, R.L.(2008).Military Load Carriage: the effect of increased load, gender and load carriage duration on gait and posture. Master of Philosophy Thesis Loughborough University.

6. Attwells,R.L.,Birrell,S.A.,Hooper,R.H.,& Mansfield,N.J.(2006). Influence of carrying heavy loads on soldiers' posture, movements and gait. *Journal of Ergonomics*, 49(14), 1527-1537.

7. Bachkosky,J., Andrews,M., Douglas,R., Feigley,J., Felton,L., Fernandez, F., Fratarangelo, P., Johnson-Winegar, A., Kohn, R., Polmar, N., Rumpf, R., Sommerer, J., & Williamson, W. (2007). Lightening the load, report naval research advisory committee U.S naval research advisory committee (NRAC) panel on lightening the load. January-September 2007.

8. Benyus, J.M.(2002).Biomimicry: innovation inspired by nature. Harper Perennial.

9. Bigard, A.X.(2000).A biomechanical and physiological approaches for determination of optimal load distribution, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP- 056.

10. Birrell, S.A., Hooper, R.H., & Haslam, R.A. (2007). The effect of military load carriage on ground reaction forces. *Gait & Posture*, *26*(4), 611-614.

11. Bloom D., & Woodhull-McNeal. (1987). Postural adjustment while standing with two types of loaded backpack. *Journal of Ergonomics*, 30(10), 1425-1430.

12. Bossi, L.L., Stevenson, J.M., Bryant, J.T., Pelot, R.P., Reid, S.A., Morin, E.L. (2000). Solider mobility: innovations in load carriage system design and evaluation, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP- 056.

13. Bronco, M., Santos-Rocha, R., Aguiar, L., Viera, F., & Veloso, A. (2016). Kinetic analysis of gait in the second and third trimester of pregnancy, Journal of Mechanics in Medicine and Biology, 16(4),

14. Brown, S.P. (2001), *Introduction to exercise science*. Lippincott Williams and Wilkins: A Wolters Kluwer Company.

15. Browning, R.C., Baker, E.A., Herron, J.A., & Kram, R. (2006). Effects of obesity and sex on the energetic cost and preferred speed of walking. *Journal of Applied Physiology*, *100*(2), 390-398.

16. Browning, R.C., Reynolds, M.M., Board, W.J., Walters, K.A., & Reiser, R.F. (2013). Obesity dos not impair walking economy across a range of speeds and grades. *Journal of Applied Physiology*, *114*(9), 1125-1131.

17. Chambers, J.A., Hiles, C.L., & Keene, B.P. (2014). Brachial plexus injury management in military causalities: who, what, when, why, and how. Military Medicine, 179 (6), 640-644.

18. Datta, S.R., Chatterjee, B.B., & Roy, B.N.(1975). Maximum permissible weight to be carried on the head by male worker from Eastern India, *Journal of Applied Physiology*, *38*(1), 132-135.

19. Drain, J., Orr, R., Attwells, R., & Billing, D. (2012). Load carriage capacity of the dismounted combatant – a commander’s guide. *Australian Government Human Protection and Performance Division Defense Science and Technology*. 1-69.

20.Drain, J., Orr, R., Billing, D., and Rudzki, S. (2010). Human dimensions of heavy load carriage. Land Warfare Conference Brisbane Convention and Exhibition Centre Brisbane, Queensland.

21. Economos, D. (2003). Combat load report. MCCDC-MRD USN Marine Corps Combat Development Command Material Requirements Division, Quantico, Virginia, 31 December 2003.

22. Frykman, P.N., Harman, E.A., & Pandorf, C.E. (2000). Correlates of obstacles course performance among female soldiers carrying two different leads, present at the RTO HFM Specialists’ meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP-056.

23. Gallagher, D., & Heymsfield, S.B. Muscle distribution: variations with body weight, gender, and age. Applied Radiation and Isotopes, 49 (5-6) 733-734.

24. Gatesy, S.M., & Biewener, A.A.(1991). Bipedal locomotion: effects of speed, size and limb posture in birds and humans. Journal of Zoology, 224 (1), 127-147.

25. Ghan J., Steger, R., & Kazerooni, H. (2006). System identification for the Berkeley lower extremity exoskeleton. Proceedings of the 2006 IEEE International Conference on Robotic and Automation. Orlando Florida

26. Gregorczyk, K.N., Hasselquist, L., Schiffman, J.M., Bensel C.K., Obusek, J.P., & Gutekunst, D.J. (2010). Effects of a lower body exoskeleton device on metabolic costs and gait biomechanics during load carriage. Ergonomics, 53(10), 1263-1275.

27. Harman, E., Han, K., Frykman, P. (2000). Load –speed interaction effects on the biomechanics of backpack load carriage, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP-056.

28. Hauschild, V., Roy, M.T., Grier, T., Schuh, A., & Jones, B.H. (2016). Foot marching, load carriage, and injury risk, Army Public Health Center (APHC) technical information paper number 12-054- 0616. May 2016

29. Holewijn, M., & Meeuwsen. (2000). Physiological strain during load carrying: effects of mass and type of backpack, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP- 056.

30. Jennings, B.M., Yoder, L.H., Heiner, S.L., Loan, L.A. Bingham, M.O. (2008). Solders with musculoskeletal injuries. *Journal of Nursing Scholarship*, 40(3), 268-274.

31. Johnson, R.F., Knapik, J., & Merullo, D. (1995). Symptoms during load carrying: effects of mass and load distribution during a 20km road march. *Perceptual Motor Skills, 8*1(1), 331-338.

32. Johnson, R.C., Pelot, R.P., Doan, J.B., & Stevenson, J.M. (2000). The effect of load position on the biomechanical and physiological measure during a short duration march, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP- 056.

33. Kaufman, K., Brodine, S., & Shaffer, R. (2000). Military training – related injuries: surveillance, research, and prevention. *American Journal of Preventive Medicine*, *18*(3), 54-63.

34. Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Journal of Ergonomics*, *28*(9). 1347-1362.

35. Knapnik, J., Johnson, R., Ang, P., Meiselman, H., Bensel, C. (2017). Road march performance of special operations soldiers carrying various loads and load distributions .US Army Research Institute of Experimental Medicine [Document], Natick, Massachusetts. 1-116

36. Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Applied Ergonomics*, 27(3), 207-216.

37. Knapnik, J. Ang, P., Meiselman, H., Johnson, W., Kirk, J., Bensel, C.K., Hanlon, W.(1997). Solider performance and strenuous road marching. *Military Medicine*, *157*(2), 64-67.

38. Kram, R. (2000). Load lugging locomotion: lesson from Indigenous people, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP-056.

39. Kunzig, R. (2001). The physics of walking: why humans walk like an imperfect pendulum. *Discover*, *22*(7) 1-4.

40. Kuo, A.D. (2001). A simple mode of bipedal walking predicts the preferred speed-step length relationship. Transactions of ASME, *123,* 264-268.

41. Legg, S.J. & Mahanty, A. (1985). Comparison of five modes of carrying a load close to the trunk. *Journal of Ergonomics*, 28 (12), 1653-1660.

42. Ling, W., Axen, K., Houston, V.(2000). The influence of load carrying methods on gait of health women, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP-056 Magee, D.J., Zachazewski, J.E., Quillen, W.S., & Manska, R.C.

43. Mawashi (2009). *Novel Load Carriage Approach*. Mawashi Protective Clothing Inc. 1-9. Load Carriage Government of Canada.

44. Mawashi. (2010). Dismounted solider load carriage: thinking outside of the box. Government of Canada/Gouvernment du Canada- Load Carriage Technology –Icee-W/eeCI-W.

45. Mawashi. (2012). Exoskeleton: project tergum. Mawashi Protective Clothing Inc.

46. Mawashi. (2017). UPRISE tactical exoskeleton. Mawashi Protective Clothing Inc. http://www.mawashi.net/en/uprise-tactical- exoskeleton

47. May, B., Tomporowski, P.D, & Ferrara, M. (2009). Effects of backpack load on balance and decisional processes. *Military Medicine*, *174*(12), 1308-1312.

48. McGregor, M., & Lovi, M. (ed.) (2010). Australian Army Journal: for the profession of Arms. 7(2), 1-165.

49. Occupational Injury and Illness Classification Manual (OI & ICM). (1992). *The Occupational Injury and Illness Classification Manual*, U.S. Department of Labor Bureau of Labor Statistics. December

50. Orr, R., & Pope, R. (2016). Gender differences in load carriage injuries of Australian army soldiers. BMC Musculoskeletal Disorders, 17, 1-8.

51. Orr, R., Pope, R., Johnston, V., & Coyle, J. (2010). Load carriage: minimizing soldier injuries through physical conditioning – a narrative review. Journal of Military and Veterans Health

52. Orr, R.M, (2011). Load Carriage and its force impact. *Australian Defense Force Journal, Journal of the Australian Profession of Arms*, 1(185), 52-63.

53. Orr, R.M. (2012). Solider load carriage: a risk management approach, A thesis submitted for the degree of doctor of philosophy, The university of Queensland March 2012, School of Health and Rehabilitation Sciences.

54. Orr, R.M, Pope, R., Johnston, V., & Coyle, J. (2013). Solider occupational load carriage: a narrative review of associated injuries. International Journal of Injury Control and Safety Promotion. DOI: 10. 1080/17457300.2013.833944. 1-9.

55. Orr, R., (2017). Military History: The History of Soldier's Load*. Australian Army Journal.* 7(2), 67-88.

56. Orr, R.M., Pope, R., Johnston, V., & Coyle, J. (2013). Solider occupational load carriage: a narrative review of associated injuries. *International Journal of Injury Control and Safety Promotion*, 1-11.

57. Pandorf, C.E., Harman, E.A., Frykman, P.N., Patton, J.F., Mello, R.P.& Nindl, B.C. (2000). Correlates of load carriage performance among women, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP-056.

58. Payne, E. (2010). Factors associated with the high burden of injuries in the Canadian forces. *Injury Prevention, 16*(Suppl 1),A156-A156

59. Polcyn, A.F., Bensel, C.K., Harman, E.A., & Obusek, J.P.(2000). The effects of load weight: a summary analysis of maximal performance, physiological, and biomechanical results from four studies of load carriage systems, present at the RTO HFM Specialists' meeting on soldier mobility: Innovations in Load a Carriage system, Kingston, Canada, June 27-29 2000. RTO MP- 056.

60. Reed, P.A. (2003). A paradigm shift: biomimicry is a new way of linking the human0made world to the natural world. *The Technology Teacher,64*(4), 22-28.

61. Reynolds, K.L., White, J.S., Knapik, J.J., Witt, C.E., & Amoroso, P.J. (1999). Injuries and risk factors in a 100-mile (161 km) infantry road march. *Preventative Medicine*. *28* (2), 167-73.

62. Richardson, K. (2017). Why people store fat in different parts of the body. Natural Intense Persona Training Blog. http://www.naturallyintense.net/blog/weight-loss/why-people-store- fat-in-different-parts-of-the-body/

63. Ricciardi, R., Deuster, P., & Talbot, L.A. (2008). Metabolic demands of body armor on physical performance in simulated conditions, *Military Medicine*, *173*(9), 817-824.

64. Roy, T.C., Knapik, J.J., Ritland, B.M., Murphy, N., & Sharp, M.A.(2012). Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviation, Space and Environmental Medicine*, 83(11), 1060-1066.

65. Roy, T.C., Ritland, B.M., & Sharp, M.A. (2015). A description of injuries in men and women while serving in Afghanistan. *Military Medicine*, 180(2), 126-131.

66. Sanders, J.W., Putnam, S.D, Frankkart, C., Frenck, R.W, Monteville, M.R., Riddle, M.S., Rockabrand, D.M., Sharp, T.W., & Tribble, D.R. (2005). Impact of illness and non-combat injury during operations Iraqi freedom and enduring freedom (Afghanistan). *The American Journal of Tropical Medicine and Hygiene*,

67. Schiffman, J.M., Gregorczyk, K., Hasselquist, L., Bensel, C.K., Frykman, P., Adams, A., & Obusek, J.P. (2010). Can a lower body exoskeleton improve load –carriage march and post march 1464: Board#120 June 9:30-11a.m. Medicine &Science in Sports & Exercise, 42(5), 283-

68. Schiffman, J.M, Gregorczyk, K.N, Bensel, C.K, Hasselquist, L., & Obusek, J.P. (2010). The effects of a lower body exoskeleton load carriage assistive device on limits of stability and postural sway. Ergonomics, 53(10), 1263-1275.

69. Sealy, J. (2015). Biomechanics of load carriage-historical perspectives and recent insights. Journal of Strength and conditioning Research, 129-33.

70. Seungnam, Y., Changsoo H., & Ilje, C. (2014). Design considerations of a lower limb exoskeleton system to assist walking and load –carrying of infantry soldiers. Journal of Applied Bionics and Biomechanics, 11(3), 119-134.

71. Shrock, P.(2008). Exercise and physical activity during pregnancy. The Global Library of Women's Medicine. https://www.glowm.com/section_view/heading/Exercise%20and%20Physical%20Activity%20During%20Pregnancy/item/98

72. Shoenfeld, Y., Shapiro, Y., Portugeeze, D., Modan, M., & Sohar, E. (1977). Maximal backpack load for distance hiking. *Journal of Sport Medicine,* 17, 147-151.

73. Soule, R.G., & Goldman, R.F. (1969). Energy cost of loads carried on the head, hands, or feet. Journal of Applied Physiology, 27(5), 687-90.

74. Task Force Devil. (2003). The modern warrior's combat load, dismounted operations in Afghanistan, Task Force Devil, Coalition Task Force 82, Coalition Joint Task Force 180, operation enduring freedom III, April-May 2003.

75. Taylor, N.A., Peoples, G.E., & Petersen, S.R. (2016). Load carriage, human performance, and employment standards. *Applied Physiology, Nutrition and Metabolism*, 41(6), S131-47.

76. Technical Bulletin Medical 592 (TB MED592). (2011). Prevention and control of musculoskeletal injuries associate with physical training, Headquarters Department of the Army, Washington, DC. 1 May 2011, 1-78.

77. Townsend, S.J. (1994). The factors of soldier's load, Thesis presented to the faculty of the U.S. Army command and general staff college. Master of Military Art and Science

78. Volpe-Ayub, B., & Bar-Or, O. (2003). Energy cost of walking in boys who differ in adiposity but are matched for body mass. *Medicine and Science in Sports and Exercise*, *35*(4), 669-674.

79. Winter, D. (2009). Biomechanics of motor control of human movement. John Wily and Sons Inc., New Jersey.