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Effects of Pack Weight on Endurance of Long-distance Hikers

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by

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Abstract

Hikers attempting long-distance trails, like the Appalachian Trail, load their backpacks down with gear that may exceed ideal limits on pack weight. Hikers pack clothing to deal with changing weather conditions, sleeping bags, tents, tarps, cooking gear, food, water and other accessories to compensate for the lack of comfort in the remote wilderness. These heavy weights may affect hikers' ability to walk in comfort and result in physical injuries such as ankle sprains, knee pain, muscular fatigue, and soft tissue damage. Heavy pack weights can cause injuries and possibly prevent hikers from completing long distance hikes.

This study evaluated pack weight to understand the limits of long-term load carriage. Participants were Appalachian Trail hikers who attempted to complete the entire trail in the 2012 season. Hikers were asked to complete a series of online surveys throughout the duration of their hike to assess pack weight, body weight, injuries/illnesses sustained, miles hiked, and reasons for quitting a long-distance hike. Through logistic regression analysis an equation for the prediction of completing the trail was developed. The evaluations of pack weight, load percentage of total body weight, average miles hiked per day, Body Mass Index (BMI), experience, and gender revealed how they affect the prediction process. The independent variables used for prediction show interdependency throughout the analysis with moderate relationships that would be required to successfully predict a hiker to complete the trail.

In addition, there was supporting data that reflected higher instances of pack related injury reports to hikers who carried heavier pack weights. This study illustrates trends in pack weight and load percentages that may provide useful in suggesting weight limits to increase the

success rates of hikers and reduce injuries. The hypothesis that hikers were negatively affected in the number of miles hiked as pack weight increases was supported in the study.

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List of Abbreviations

AT	Appalachian Trail
ATC	Appalachian Trail Conservancy
BMI	Body Mass Index
CDT	Continental Divide Trail
DNRF	Did Not Report Finishing
EFA	Exploratory Factor Analysis
LP	Load Percentage
MIL STD	Military Standard
NOBO	North-bounder
PCA	Principle Component Analysis
PLS	Pack Load Score
PW	Pack Weight
RC	Reported Complete
REI	Recreational Equipment Incorporated
SOBO	South-bounder
TBW	Total Body Weight

Introduction

When deciding to take a six-month journey on a long-distance hiking trail, hikers have to take several factors into consideration. The constant exposure to weather, terrain, wild animals, hunger, injuries, sickness, isolation from society, independence of technology, and, on most days, less than comfortable conditions should be at the forefront of every hiker's mind when deciding to take the trip.

The activities of a hiker in the wilderness are more than just simply walking. They must first meet their basic needs for food, water, shelter, and sleep. Because most long-duration hikers carry all of these supplies on their back, the choice of backpack type, and how that pack is loaded, plays a major role in a hiker's comfort and probability of completing the hike. Furthermore, carrying heavy loads can lead to injury. As shown in a study at Shenandoah National Park, hiking is the most common activity that triggered injuries and illnesses (Forrester & Holstege, 2009). Other studies show that backpack-related injuries include foot blisters, lower back pain, chronic joint pain, compression of cervical spinal nerves known as rucksack palsy and paresthesias, a temporary numbing sensation affecting the legs, arms and feet (Boulware, 2003; Knapik, Harman, & Reynolds, 1996).

In order to avoid these kinds of injuries there are a number of generalized weight limits that are recommended by various experts, studies, and organizations. Most backpacking experts have lived by the rule of thumb of 30%, or one third, of the hiker's body weight as a standard weight limit to caution potential hikers (Ray, 2009). These limits may have originated from military standards where 30% of total body weight is the standard for military in close combat operations and 45% for marching operations (U.S. Department of Defense, 1999). Other literature suggests weight limits of no more than 20% of total body weight should ever be carried by anyone (Illinois State Board of Education, 2006; Tousignant, 1999). However, there are insufficient data on the suggested limits for long-term load carriage that would suppress injuries to hikers and prevent them from prematurely ending their backpacking trip.

This study examines pack weights and how it affects a hiker’s ability to complete a long-distance trail, such as the Appalachian Trail (AT). This study also reviews injuries sustained in previous studies by AT hikers and attempts to provide additional data for this domain. The factors that can influence a hiker’s endurance are also explored. The primary focus of the study was to collect survey-based data from hikers to identify pack-load limits for long-distance hikes like the AT based on pack weight and load percentages of total body weight.

Thru-hiking the Appalachian Trail

Every year hundreds of hikers head to Springer Mountain in Georgia to attempt to hike the AT. The trail travels north from Georgia through 14 states until it reaches the top of Mount Katahdin of Baxter State Park in Maine; a total of 2,181 miles in the 2011 season. Since 2005, an average of 1,350hikers each year register with the Appalachian Trail Conservancy (2011), or ATC, to attempt a “thru-hike” of the AT, that is, they make an attempt to hike the trail in its entirety in a single calendar year. These hikers are known on the trail as North-bounders (NOBOs). In contrast, South-bound hikers (SOBOs) start at the northern terminus at Mount Katahdin and make up an estimated yearly average of 250 registered hikers. Regardless of direction, only about 50% of all hikers make it halfway to Harpers Ferry, West Virginia.

Furthermore, only a quarter of the starting hikers make it to the end points of the AT, either in Maine or Georgia.

AT hikers have different motives for making such an arduous journey. Each individual has their own driving force that brought them out to the AT, helps them through each day, and mentally sees them through to the end. The motivations of many long-distance hikers were explored in a study on the West Highland Way in Scotland (den Breejen, 2007). Some wanted to relax mentally, get away from the real world, and be close to nature. Others found it self-fulfilling to challenge themselves and discover a sense of accomplishment. Another study on solo-hiking described that many hikers enjoy setting their own pace and the solitude of being on a hiking trip alone (Coble, Selin, & Erickson, 2003). All these reasons could easily be related to by everyone who takes their first steps on the AT, but the real motivation for staying on the trail continuously for months and overcoming the many obstacles hikers face may be more of a mental challenge. As Davis (2012) points out, hikers should continuously remind themselves the reasons for hiking the trail in order to maintain the mental posture for success.

The AT presents many obstacles that can break hikers' inspirations for being on the trail and cause them to quit prematurely. Hikers spend many days in bad weather, deal with physical injuries, and sometimes sickness. Every day to the hiker can be a physical struggle. The attrition rates are so high because most hikers are not properly prepared to deal with weather changes, hunger, water filtration, terrain, and, at times, the loneliness of being in the remote wilderness away from everyday life. Accordingly, in an attempt to be prepared, many hikers do not do the proper logistical planning and tend to over pack.

Unless the hiker is experienced in wilderness living, a thru-hike of the AT requires months of logistical planning for seasonal gear changes and food resupplies to maintain energy on the trail. There are many aspects to the logistics involved, but one of the most critical is in the gear chosen by hikers for use on the trail. The base weight of a pack is the total weight of all the gear carried in the pack except for food, water, toiletries, and other consumable items (Ray, 2009). Three items that make up the majority of base weight are the sleeping bag, the tent, and the backpack itself. Each of these items can be viewed as its own separate system as they can be replaced by a variety of products that perform the same functions with vastly different features. When designing lightweight gear, manufacturers use lighter materials that tend to be more expensive than their heavier counterparts, passing the costs on to the consumers. The result is that long distance hikers usually select gear that will be tailored to their very specific needs according to use, weight, and their budgetary limitations.

Gear systems commonly found on the hiker are sleep, shelter, cooking, water filtration, clothing, hygiene, and the backpack itself. Clothing, sleep and shelter systems are built for keeping hikers comfortable and warm to prevent deadly conditions such as hypothermia (Coyle, 1999). Water filtration systems help keep hikers from drinking contaminated water and contracting water-borne illnesses such as giardiasis and cryptosporidiosis (Welch, 2000). However, since backpacks are the major component to carry large loads, this system is likely to leave hikers susceptible to various physical injuries such as ankle sprains, knee pain, muscular fatigue, and soft tissue damage. When considering the issues that can come from using a backpack, a review of the general procedures for proper fit, pack weight, and pack weight distribution must be practiced by hikers.

Backpack Fit

The first variable to consider in properly fitting a pack is the sex of the pack wearer. Backpack manufacturers today are creating packs that can be adjusted to fit male and female hikers in addition to creating new models of packs built specifically for women. The reason for the special backpacks has to do with the different shape women have in the chest and pelvic regions. Women have a wider pelvis and more pronounced iliac crest, the curved ridge at the top of the pelvic bone, than men (Lafiandra & Harman, 2004). In a previous study the differences between men and women in the waist area were apparent as women complained of more discomfort with the straps and hip belt (Harper, Knapik, & de Pontbriand, 1997). The testers in that study used military type backpacks with no differences built in for female wearers. However, in another study where women were using their own packs specifically fitted for them, the percentages of injuries were not significantly different from that of men except for paresthesias; a temporary numbing in the limbs (Boulware, 2004). Accordingly, female hikers are advised to get a pack made specifically for women.

Hikers are urged to get measured for packs as the right fit can make the journey much easier. T.D. Wood, backpack expert at the outdoor equipment company REI, says that the torso length is one of the most important features in getting fitted for a backpack along with a snug fit on the hips (Wood, 2010). Hikers who purchase their backpacks off the Internet as new or used items limit their ability to be fitted properly. An improperly fitted pack could cause injuries to hikers that require time off from the trip. One of the most frequent injuries with backpack usage is lower back pain. Repeated strains of the back slowly aggravate the lower lumbar region while the normal daily workloads continue, until the pain occurs (Kroemer, Kroemer, & Kroemer-

Elbert, 2003). Injuries that cause muscles to overwork due to weight not being properly shifted to other areas of the body (Lafiandra & Harman, 2004) could be serious enough for a hiker to stop hiking the trail in order to recover from the injury. Other issues exist in picking a backpack for comfort like knowing how much weight will be carried on a day-to-day basis. Hikers should also know how to use the adjustment straps to have the pack contoured to the body.

Most backpacks have five adjustments points (see Figure 1) to properly carry a load or make adjustments as the terrain requires. The hip belt has a strap to tighten the pack to the waist. This strap is usually tightened the most to prevent movement and shifting of the carriage load. A sternum strap connects across the hiker's chest to adjust the load to rest on either midline muscles or lateral portions of the shoulders (Knapik, Reynolds, & Harman, 2004). The shoulder straps can be loosened or tightened depending on the need to lift the load from the hips to the shoulders (Knapik et al., 2004). Load lifters are usually attached to a backpack at the top of the pack and the back of the shoulder straps. Their purpose is to keep the pack close to the upper body instead of placing the weight on the lower lumbar region. Stabilizer straps can usually be found on the backside of a hip belt connected to the lower part of the pack and tighten to the pack to the lower lumbar region for balance. These straps can be loosened when going over rough terrain to allow the bottom of the pack free movement to prevent the waist from being constricted.

Figure 1. How to adjust a backpack. The adjustment straps on a typical backpack are used to keep the user comfortable by shifting the load onto various parts of the body. First tighten the hip belt (1) by pulling forward to get the pack snug around the waist. Then clip and tighten the sternum strap (2) to bring the shoulder straps into a comfortable position across the shoulders. Then cinch down the shoulder straps (3) to adjust the weight held on the shoulders. Using the load lifters (4) the hiker can adjust the closeness of the pack to the upper back. This adjustment is important when going up steep terrain. A 45-degree angle is typically suggested. Then to keep the bottom of the pack close or away from the lower back, adjust the lower stabilizer straps (5) by pulling them forward.

A backpack's hip belt is designed to carry a portion of the carriage load if worn properly. The body's natural ability of the trunk muscles to develop vector forces that pull into the hips causes some spinal compression (Kroemer et al., 2003). Tightening the hip belt to a snug fit on the hips helps transfer the pack weight from the shoulders to the lower part of the body reducing that compression. It is estimated that the hip belt can provide a weight savings from the upper back of about 30% of the pack weight based on studies of military packs and carriage loads (Lafiandra & Harman, 2004). When properly fitted and adjusted, the weight of the pack can feel more comfortable if carried on the hips as some individuals indicated in a study on hip belts and stability (Sharpe, Holt, Saltzman, & Wagenaar, 2008). Increased padding on hip belts helps in minimizing discomfort from loads pressing against the nerves of the anterior iliac spine of the lower lumbar region causing paresthesias in the thighs (Boulware, 2003) and pain in other areas of the waist. Another advantage of using a backpack with a hip belt is that it can control the rotational torque forces associated with heavy loads and the movement of the torso (Sharpe et al., 2008). Biomechanical tools have even been developed in order to capture the impact of a backpack hip belt system on the human torso (Bryant et al., 2004). Backpacks that have been made flexible through an internal frame and padded hip belts have also been found to provide energy savings to hikers as the oscillations of the pack stay nearly in phase with the motion of the trunk of the body (Foissac, Millet, Geyssant, Freychat, & Belli, 2009). Hip belts have become an important feature for backpacks in preventing the wearer from developing serious injuries if fitted, adjusted, and worn properly.

Pack Weight

Every backpack has a weight limit that is suggested by the backpack manufacturer based on the design and testing of the pack load capacity. For hikers who put too much weight into a pack, there are risks of injury and pack failure. An overloaded backpack can cause injuries since the weight may be shifted to other parts of the body like the legs, back, or shoulders. Backpacks loaded to carry weights heavier than the maximum load capacity could stress the seams, shoulder straps, and hip belts of the pack causing the carriage system to wear out sooner than expected. The maximum load capacity was created by manufacturers to avoid these pack failures.

Pack weights are usually categorized based on the descriptions of various industry experts. While the expert opinions vary on the category names, there is a rough consensus on the weight categories for backpacking. Pack weights for traditional hikers are usually higher than 30 lb (Wood, 2010). For lightweight hikers, pack weights range from 20 to 30 lb. Ultralight hikers have packs that weigh 12 to 20 lb. There is also a growing interest in minimalist backpacking in which hikers carry less than 12 lb.

The primary items that go into the pack are sleeping bag, tent, cooking pot, utensil, stove, water filter, clothing, and toiletries. Any other items that hikers bring are strictly personal preferences. However, when those items accumulate so do the ounces in the total pack weight. One example of this comes from solo-hikers who were surveyed for the items they carried for protection. Some inexperienced hikers admit to carrying a gun or chemical pepper spray for protection from animals or other people (Coble et al., 2003). Experienced thru-hikers would say that the extra weight is just not necessary since personal protection products are rarely used.

Many experienced hikers spend hours helping new thru-hikers in keeping pack weights down. Results in a web search on Google using the key words “pack weight” produce a majority of links dedicated to backpacking and pack weight reduction. This trend to shave ounces off the total pack weight has become the primary part of gear research for potential backpackers.

While there is not a lot of data to support a specific pack weight limit for backpacks, there is the basic rule of thumb that is shared by many hikers. That is to keep pack weight down to a maximum of 30%, or one third, of the total body weight (Ray, 2009). According to literature from the Illinois State Board of Education (2006) on children backpack weights no one should carry more than 25 lb in a backpack, including adults. If using the 30% of total body weight generalization, a 200 lb man would be able to carry 60 lb in pack weight. When subscribing to the 25 lb weight limit, hikers with a body weight of 200 lb would be carrying less than 15% of their total body weight. A study of women out for short day hikes using various load weights (20%, 30%, and 40%) have shown that smaller loads provide less chance of injury (Simpson, Munro, & Steele, 2011). However, these tests still do not provide enough quantitative research into hikers sustaining these load carriages over long periods of time.

One study that tested heavy pack weights on soldiers for a long, multi-day march showed that they had low reports of injuries associated with pack weights (Reynolds, White, Knapik, Witt & Amoroso, 1999). That study used 218 light infantry soldiers on a 100-mile march carrying an average of 103 lb each. They reported 78 (36%) of their participants complaining of injuries, with only 4 listed as back strains. For the heavy weight carried, this report of injuries is very low even for the physically fit soldiers used in the study. Related studies in injury reporting conclude that possible reasons for low reports are for fear of discipline (Groover, Krause, & Hidley, 1992) and the belief that pain was an ordinary consequence of the activity (Pransky, Snyder, Dembe, & Himmelstein, 1999). In this study, the risk of hikers under-reporting injuries was very low since the hike and weights they carried were not forced on them.

By using a more precise method for assessing the most common pack weights in conjunction with the load percentage (LP) of total body weight, a trend may be apparent in physical injuries that may be due to pack weight. Most hikers will have a body weight between

100 and 300 lb. Figure 2 shows a graphical representation of load percentage groups as calculated from the total body weight and pack weight of hikers. Hikers were expected to be most commonly carrying 20 to 30 lb during the study.

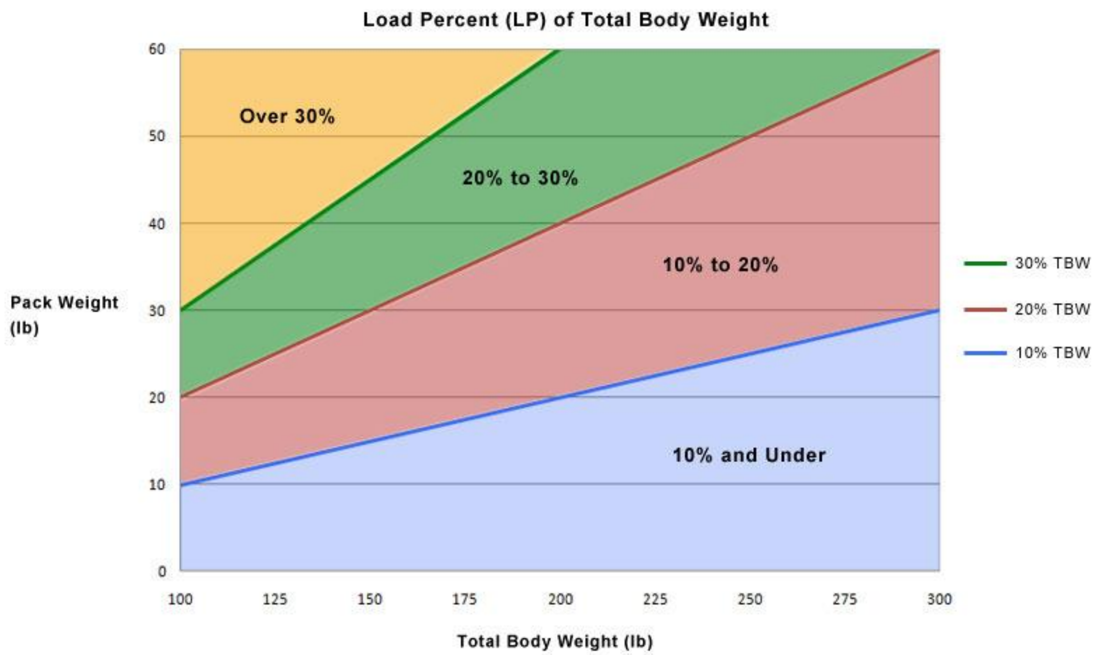

Figure 2. Load percentage of total body weight chart. This chart depicts the load percentages (LP) of total body weight (TBW) according to the pack weight and body weight of the individual hiker. Plotting hikers accordingly in this graph could produce a trend in pack weight. Hikers were expected to be carrying common pack weights between 20 and 30 lb.

Pack loads that are over the average ranges should be considered heavy and may need to be reduced in weight. There are several ways a hiker can reduce weight to their packs. They can replace existing gear with lighter versions of equal or better quality. They can limit their loads to only the things they need. Hikers who carry unnecessary items soon learn from the mistake and eventually mail the items home or throw them out. Using items that have multiple uses can save space in a pack as well as weight, for example using a down quilt to sleep in and as a jacket in camp. Hikers who are not traveling alone may be able to share equipment. One hiker can carry the two-man tent and the other a single cook set. These are ideas that help in keeping weight down, but it does not exclude a hiker from injuries from carrying weight.

One other option to help hikers mitigate issues with heavier loads is with the use of trekking poles. The use of two trekking poles have been shown to be more beneficial for maintaining balance while carrying a load than using one pole or none (Jacobson, Caldwell, & Kulling, 1997). Trekking poles provide better balance since they provide additional contacts to the ground surface that allow a hiker to better maintain their composure on loose or uneven ground. Hikers can use the poles to push off objects, protect them from falls and cushion the forces that would normally act on the knee and ankle joints. Trekking poles are most beneficial during downhill grades as they are effective in reducing the muscle activity around the lower joints and limiting the loading on the hips (Bohne & Abendroth-Smith, 2007).

Studies with students that use backpacks to carry loads on a daily basis have shown that the frequent use of packs cause pain in the lower back region (Heuscher, Gilkey, Peel, & Kennedy, 2010; Moore, White, & Moore, 2007). Almost half of the younger children in the first study were shown to have increases in back pain when pack weights were over 10% of their body weight. Meanwhile, college students who participated in the second study had shown a 25% increased risk of annual low back pain for each 4kg (approximately 9 lb) of pack weight. However, this study did not find supporting evidence of an increased risk of lower back pain when students carried more than 10% of their body weight. These studies might suggest that younger children whose bodies are still in development stages may be more affected by pack weights over 10% of their body weight than adults. This may differ for adults who are more developed and capable of carrying heavier loads.

Adult military operators have been using set standards for pack weight limits for over ten years developed by the U.S. Department of Defense. Military Standard (MIL STD) 1472-F allows soldiers to carry up to 30% of their total body weight (TBW) during combat operations (U.S. Department of Defense, 1999). The military pack weight limit of 30% TBW should not be compared to the 30% TBW a hiker would carry since the function of the military pack is to carry mission critical gear and soldiers are better conditioned for carrying that weight. The same military standard specifies that military personnel are allowed to carry up to 45% of TBW during marching operations, well over the weight that hikers would carry in a similar function while hiking the AT. In one study using infantry soldiers, prolonged load carriage with loads up to 45kg (100 lb) resulted in injuries in the form of blisters, stress fractures, back strains, metatarsalgia, and rusksack palsy (Knapik et al., 2004). These heavy loads would seem to exceed the standards of 45% of TBW during marching operation and justifies the military standard.

One study that used a higher LP than the 30% of TBW tested loading conditions of lower body joints with weights up to 40% of TBW (Simpson et al., 2011). Their results showed that women who carried 40% of their TBW alter their knee joint loading and posed an injury risk, suggesting a limit of 30% of TBW. However, their study did not include service men or women conditioned to carry such weight which may have produced different results. A study on balance and decisional processes while carrying a LP equal to 30% of TBW suggested that balance was significantly affected by the weight after several 22-min trials (May, Tomporowski, & Ferrara, 2009). This would suggest that the generalization of a pack weight limit of 30% of TBW may not be sufficient for hikers in reducing injuries.

Distribution of Pack Weight

Another aspect of proper backpack usage comes from the distribution of the weight packed into the load carriage system. By placing bulkier items at the bottom of the pack, like the sleeping bag and sleeping pad, this allows for the heavy items to be higher in the pack. Food and water account for the majority of pack weight and should be packed last.

Placing the weight into the pack in a particular position is important depending on the function being carried out by the hiker. Hikers that are traveling uphill on a grade usually will place the majority of the weight higher in the backpack to change the center of mass. Studies suggest that by setting the pack weight’s center of mass higher in the pack, the position can offset the workload needed to carry the pack (Knapik et al., 2004; Liu, 2007). When evaluating the energy costs of the distribution of pack weight, one study found supporting evidence that when the center of mass of the pack is carried on the upper back, the energy costs are much lower than having the center of mass over the lower back (Abe, Muraki, & Yasukouchi, 2008). Lowering oxygen consumption also plays a role in reducing the workload during backpacking when the center of mass of the pack is located in a higher position, but only in level grades.

There are trade-offs in having the center of mass higher in the pack; the hiker may become more unbalanced on rocky terrain than with a lower center of mass (Knapik et al., 2004). Lung function also may be affected while going uphill by the high placement of the heavier items higher in the pack (Liu, 2007).

While a lower center of gravity in line with the body's lower back and lumbar region could cause the workload to increase, it may be necessary to change the distribution of the weight during certain terrain changes. Traveling over rocky ground with a high center of mass may cause balance problems, so placement of the heavier items in the backpack may become dependent on the grade of the terrain (Liu, 2007). Regardless of the placement of the weight, additional loads of up to 30% of total body weight disrupted balance and degraded some cognitive functions of situational awareness (May et al., 2009).

Factors That Affect Completing a Thru-hike

Committing to a thru-hike for many hikers is a change in lifestyle. Hikers leave behind much of today's technology to live in the wild for many months. These changes affect their ability to complete the trail if not properly planned for. For instance, humans do not normally walk for extended distances day after day with weight strapped to their backs. This can cause a variety of injuries while the body gets accustomed to hiking over several weeks.

Common injuries reported from long-distance hikers are musculoskeletal injuries which include acute joint pain, numbness, back pain, tendonitis, stress fractures, and rucksack palsy (Boulware, Forgey, & Martin, 2003; Gardner & Hill, 2002; Knapik et al., 1996). One of those musculoskeletal related injuries is paresthesias or a numbness that can be felt in the thighs or the feet (Anderson et al., 2009). This is caused by over tightening of the hip belt which then presses against the lateral femoral cutaneous nerve, a nerve responsible for sensation in skin, trapping it against the anterior iliac spine (Boulware, 2003). While most musculoskeletal injuries can be attributed to carrying a heavy load in a backpack, there is no defined weight limit that can act as a predictor to the onset of such ailments.

Another frequent injury due to carriage load is soft tissue damage, much like what was reported by soldiers as blisters due to heavy pack loads (Knapik et al., 2004). Skin chaffing around the waist area is also very common (Boulware et al., 2003) and causes irritation to some hikers as they will need to add padding or change gear to avoid the problem.

Other studies indirectly suggest that pack weight can be related to injuries of hikers. Some acute injuries that have been reported by students in outdoor leadership training include muscular damage, soft tissue damage, ankle, and knee injuries (Hamonko, McIntosh, Schimelpfenig, & Leemon, 2011). Researchers in that study found no supporting evidence that these injuries were related to pack weight even though the average pack weight per student was more than 50 lb and a third of their mean total body weight of 150 lb. If these tested weights are equivalent to the generalized limits of 30% of total body weight, then load limits to produce a safe hike with fewer injuries must be less then often recommended limits.

Hikers also experience many other ailments that are not related to pack weight and deserve to be mentioned in the study as they may prove to be factors that can limit hikers from completing the trail. Illnesses such as giardiasis, hypothermia, and Lyme disease have been common to AT hikers and pose serious threats to hikers.

Gastrointestinal illnesses such as giardiasis (Welch& Welch, 1995) have long been thought to be caused by drinking contaminated surface water. However, giardiasis has been linked to poor hygiene (Welch, 2000) and can cause hikers to experience diarrhea for days after contracting it. Diarrhea is the leading infectious illness found in hikers where over 50% become affected (Boulware, 2006) at some point during their hike. It is recommended that hikers practice good hygiene techniques while in the wilderness.

Some hikers experience dehydration on the trail from not drinking enough water. In some cases dehydration can lead to hypothermia and can impair the performance of a hiker (Coyle, 1999). Dehydration combined with cool air and the moisture in a hiker's clothing can be enough to decrease the body's core temperature below normal levels (Giesbrecht, 2001). Drinking water can help decrease the chances of dehydration leading to hypothermia. Hikers who know how to layer their clothing have a better chance of stabilizing body core temperatures.

Lyme disease is debilitating to anyone who gets bitten by an infected tick. A previous study on the AT for Lyme disease has only shown very small percentages of hikers being affected even though it was the most prevalent vector-borne disease (Boulware et al., 2003). It might be concluded that hikers take extra precautions to guard against Lyme disease with frequent tick checks, chemical treatment of clothing with Permethrin, or through the use of bug sprays that contain DEET.

Some AT hikers that experience one or more of these illnesses make a choice to continue on with their trip, even if faced with long recovery times. Those that ended their journey due to illness may have had a hard time recovering or even finding the inspiration to keep going.

How a hiker psychologically feels on their journey could also be an important factor in completing the trail. Davis (2012) felt the psychological aspect was his greatest obstacle and was the most compelling subject to write about. Davis, being an experienced hiker shares his advice to help others combat the mental challenge of the hike. By this study collecting the factors that influenced hikers to quit early, possible alternatives to pack weight and injuries could have been expressed by hikers. If the reasons were related to pack weight then the data was taken into consideration.

When speaking to experienced thru-hikers the generalization is that pack weight is the number one cause of injuries to hikers. However, there have been no studies to dispute or support that claim. Furthermore, none of the studies performed on long distance hikers have determined definitive pack weight limitations that would be considered preventative of injuries. Musculoskeletal injuries and soft tissue damage will never be completely eradicated from the ailments that hikers will experience. So by finding some trends in hiker pack weights, body weight, and injuries sustained there may be an opportunity to lessen the impact on a hiker's ability to complete a thru-hike.

Purpose of the Study

The purpose of this study was to determine if pack weight affects the completion of a long-distance hike on the AT. The endurance of the hikers was assessed through surveys as they answered questions on total miles hiked, number of days hiked, and types of injuries sustained. The data collected considers gender differences, pack weight, load percentages of total body weight and BMI.

Based on general recommendations by the backpacking industry, pack-weight limits should not exceed 30% of total body weight. According to other literature pack weights should never go over 20% of total body weight or 25 lb, whichever comes first (Illinois State Board of Education, 2006; Tousignant, 1999). These limits were tested to provide additional supporting data on necessary limitations to help avoid injuries and premature termination of a long-distance hike.

The possibility of injuries to the shoulders, back, lower joints, limbs, and soft tissue damage were assessed along with other discomfort or fatigue that could have been caused by pack weight. Information on the neurological disorder causing numbness in the legs or feet, paresthesias, was also gathered to see if there was a connection to the disorder and the pack weight or pack fit. Other common illnesses experienced in long-distance hiking such as Lyme disease and giardiasis (Boulware et al., 2003), that are not be related to pack weight, were also captured for analysis as possible causes for hikers prematurely quitting a thru-hike. In addition to having an alternative view to other factors influencing hikers, illness questions also helped conceal the goal of the study specifically focused on pack weight.

Beyond the direct effects of pack weight, surveys also captured other factors that could have contributed to hiker injuries including pack fit, footwear, and any pre-existing conditions. In order to control for possible confounds, hikers answered questions in a baseline survey to capture the pack fitting procedure used during purchase, type of footwear used, and any pre-existing conditions that should be considered for exclusion of the study. Participants evaluated themselves on the injuries they sustained during hiking and if the injuries caused the hiker to seek medical attention or take time off from the trail.

This study set out to improve on the approach used in previous studies on injuries for long-distance hikers. For example, in one closely related study, Anderson et al. (2009) used hikers from both the AT and the Pacific Crest Trail to collect data on injuries sustained during hiking. Because data were only captured at the end of those trails, the researchers did not collect data from hikers that quit prematurely due to injuries and illnesses. The same limitation in results took place in a study of hikers on the Long Trail in Vermont as results were based only on hikers who completed the trail and not those who quit early (Gardner & Hill, 2002). Another example of prior research with limitations is Boulware's study on backpack-induced paresthesias

(2003). In that study AT hikers were initially approached during a 1,000-mile stretch of the trail from North Carolina to New Hampshire and given a post card that asked basic questions that was then mailed to the researchers. Researchers later mailed a more comprehensive paper survey to hikers which required hikers to recall how they felt during their hike several months earlier adding a possible bias to the results. Still another study that showed no supporting evidence of pack weight causing injuries in hikers was limited because of the participant population and the hike duration (Hamonko et al., 2011). In that study, participants were students in outdoor leadership training hikes lasting no longer than a week or two. The weaknesses in that study that may have affected the outcome of the results include a lack of months-long exposure to the backpacks, the experience level of participants, and the unknown number of unreported injuries.

The present study improved upon these limitations in several ways. First, hikers completed surveys at multiple locations along the trail limiting recall bias. Second, data represents a long-duration hike with long-term exposure to carrying various loads by hikers with varying experiences. Third, this study includes data for hikers that not only completed the trail but also those who decided to quit early.

For the purposes of this study hikers were categorized by the load percentage (LP) of TBW. The primary hypothesis for the study was that hikers were negatively affected in the number of miles hiked as pack weight increased. Two secondary hypotheses were also tested. First, it was predicted there would be a significant difference between LP groups based on the number of miles hiked. Second, it was predicted there would be a significant difference between LP groups based on completing the trail.

Method

Initially the study was to use a single-variable, between-subjects design focused on the load percentage (LP) of total body weight (TBW) as the independent variable. However, during data analysis, this design was modified as a longitudinal study using logistic regression analysis. The change in design was found to be more efficient since data points were collected over four surveys. In addition, the confluence of additional factors was also observed that would best be used to predict the outcome of completing the trail. The new design was used to test only the primary hypothesis.

For the two secondary hypotheses, the original, single-variable, between-subjects design was used. The independent variable for the secondary hypotheses testing was the LP Category. The LP Category variable is based on the LP of TBW of each hiker and is divided into four levels: 10% and under, 10% to 20%, 20% to 30%, and over 30%.

The study treated each participant as a member of a LP category when they started their hike. If participants opted for lighter pack weights and changed their LP, they were then moved to the appropriate category in the following survey. Many hikers lost a significant amount of body weight during the hike but did not change their pack weights. The result was a higher LP and a reclassification into a higher LP category. These changes were frequent across the study.

An additional measure of hikers, based on the actual pack weight carried, was recorded to compare to the loose industry practices. The field of outdoor recreation typically categorizes backpackers by calling them lightweight, ultralight, minimalist or traditional hikers. The actual pack weight (PW) boundaries that describe these levels vary by the expert. One goal of this study was to develop an indexed list of hiker types based on the PW and/or LP hikers carried. The result was an indexed scale variable that can categorize load carriage weight for specific applications.

Data collected from hikers for starting body weight and height were used to calculate body mass index (BMI), the standard for measuring obesity levels correlated to body fat. BMI was expected to play a larger role in determining if hikers completed the trail. Its role was important in predicting completing the trail when combined with other factors, but limited as an independent variable to a supporting role that illustrated weight ratios of hikers and pack weights. There was also a relationship present with BMI and gender. The formula for BMI is shown in Figure 3.

English Body Mass Index Formula

BMI = (Body Weight in pounds / (Height in inches x Height in inches)) x 703

Figure 3. How to calculate BMI. This formula shows how BMI is calculated by the English measurement standards.

The method of categorizing hikers based on LP was expected to provide more precise measures for determining if hikers are more injury prone in certain categories. However the change in study design used both PW and LP as scaled variables for testing the primary hypothesis as opposed to the categorical variables used in testing the secondary hypotheses. Additional factors such as BMI, gender, and average miles per day played more significant roles in predicting hikers completing the trail. There were trends in what participants carried based on body weight, type, and experience that were figured into analysis and the prediction algorithm.

Participants

Participants included hikers who had already planned to hike the AT in the 2012 season. There were 117 hikers who agreed to take part in the study. Of the total hikers, 14 did not complete the registration process, 13 took the baseline survey only, and 3 were removed for not following directions. Thus, 30 hikers were removed from the study. Of the remaining 87 hikers, 3 additional hikers were also removed as possible outliers in the study. This resulted in 84 long distance hikers that completed at least a baseline survey and an additional survey during their trip. Since the participants had already chosen to hike the AT and there was no manipulation to pack weight during the study, it was determined that there were no additional risks to participants.

All participants were asked to fill out an online consent form (see Appendix A). All participants had to be at least 18 years of age and intend to thru-hike the AT. Participants were required to register on a website created specifically for this study and dedicated to the survey, Hiker Survey (http://www.hikersurvey.com). Registration required an email address, name, and a password. Hikers participating in the study were encouraged with the incentive of being placed in a random drawing at the end of the study for gift cards from outdoor outfitter stores. For hikers to participate in the random drawings they provided additional contact information at the end of the study to include full name, address, and phone number. Email reminders were sent to registered participants reminding them of their participation and forthcoming surveys.

Participants were able to drop out of the survey at any time by not filling in any additional surveys. Participants were also able to opt out of future emails on the website.

The hikers who took part in the study completed online questionnaires at various points during their trip providing data for two separate groups. These data consisted of body weights and heights, pack weights, age, gender, self-assessed limitations, injury occurrences and number of days spent hiking. Hikers age ranges were from 18 to 65 and had various experience levels. Of these hikers, 24 reported completing the trail in its entirety (28.6%), 2184 miles, and 60 participants did not report finishing the trail (71.4%). Data from hikers who did not report finishing the trail and were no longer able to participate in surveys were accounted as last recorded information. At the end of the trip, hikers were asked to complete an Exit Survey, an opportunity to collect a fourth-round dataset and trigger the end of their hike. The hikers that completed the trail all filled out the Exit Survey. An additional 10 hikers who did not complete the trail also filled out the Exit Survey signifying they quit early. Data collected from them was considered to be last recorded information and counted towards the next regional survey point. An example would be that a hiker who completed the baseline survey, one regional survey and the Exit survey is counted as completing two surveys after baseline.

Each survey illustrated a reduction in hikers participating in the study. The baseline and first survey for most hikers were taken at the same time and both represented 84 hikers. The second survey included 48 participants. The third survey had 35 participants. Only the 24 hikers who reported finishing the trail had completed all regional surveys and the fourth survey.

Surveys

Participants were asked to complete up to five surveys, one baseline survey, three trail surveys, and an exit survey (see Appendix B). The baseline survey was administered at the time of registration and may have been followed by the first trail survey. Participants were asked to complete the maximum of three trail surveys while they were on their hike. The trail surveys were spread out over 1,400 miles of the trail (see Figure 4). The first trail survey, called the Southern States Survey, was triggered between Hot Springs, North Carolina and Damascus, Virginia. The second trail survey, the Mid-Atlantic States Survey, was triggered between Front Royal, Virginia and Duncannon, Pennsylvania. The third trail survey, the New England States Survey, was triggered between Kent, Connecticut and Manchester Center, Vermont. The triggers for the survey came in the form of announcements (see Appendix C) that were posted in area hostels, hotels, outfitters, public libraries, and anywhere else free Internet access was given to hikers. The information posted on the survey announcements included website, brief information on the survey, and a Quick Response (QR) code for those who wanted to use mobile appliances to access the website. Once hikers completed the trail surveys and either completed their thru-hike or ended early, they were asked to complete an exit survey. According to the statistics (Appalachian Trail Conservancy, 2011), the attrition rate is roughly 75% and thus was expected to constitute a large population of the study.

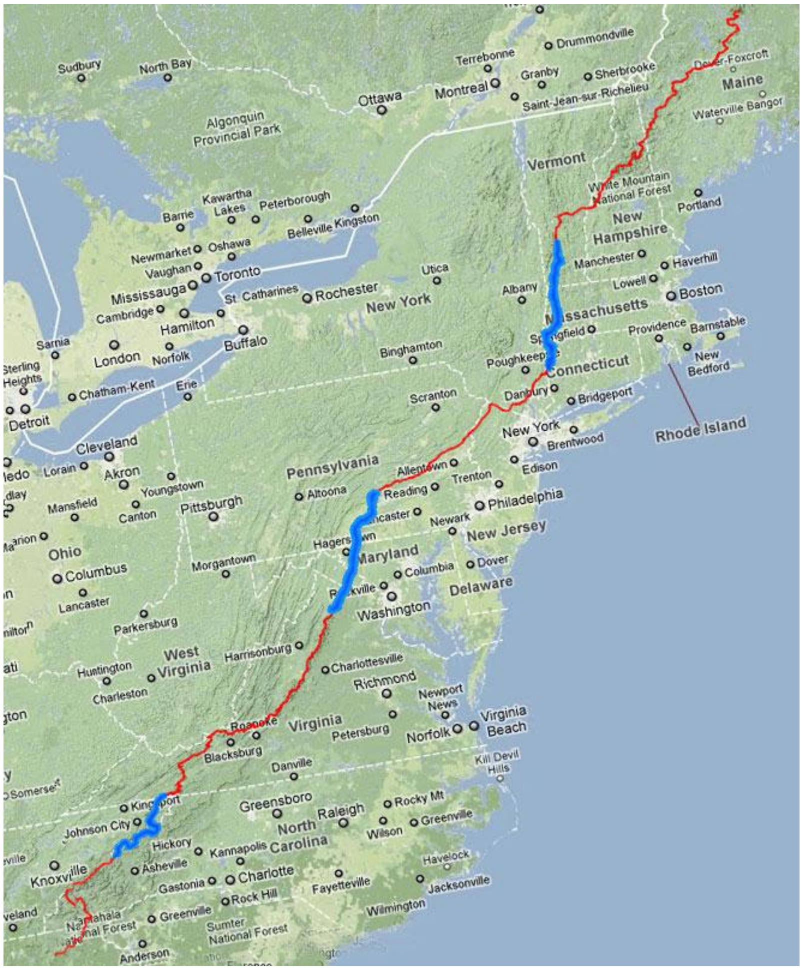

Figure 4. Survey location points on the Appalachian Trail. The trail surveys were completed in the areas where the trail is highlighted blue. The first trail survey NOBO hikers came across is the Southern States Survey in Hot Springs, North Carolina. Hikers had the opportunity to complete the survey anywhere from Hot Springs to Damascus, Virginia. The second trail survey was the Mid-Atlantic States Survey with opportunities to complete the survey starting in Front Royal, Virginia through to Duncannon, Pennsylvania. The third trail survey was the New England States Survey with opportunities to complete the survey starting in Kent, Connecticut through to Manchester Center, Vermont. The exit survey was to be completed at any time when a hiker quit the trail.

Participants in the study were asked to register before completing any surveys. This ensured that each participant could be tracked using the same user-id and email address throughout the study. The initial registration captured basic personal information like age, gender, height, weight, pre-existing conditions for specific injuries, hike start date, and backpacking experience level. Additional information on the equipment was also logged like the backpack model and pack weight. The participants in the survey had the opportunity to change the equipment used during the hike as well as average pack weight as they filled out each trail survey.

Data collected during trail surveys included questions on total hiking days, total days off, total miles hiked, current body weight, injuries, illnesses, and limiting factors to their hike. The performance abilities that are most important to the study are average miles per day and total miles hiked. Performance measures were tested against the pack weight conditions and injuries for trends.

The exit survey was the trigger for the study to know that a participant completed their thru-hike. The exit survey collected data on the final performance of the hiker like number of days to complete the trail, number of days off, injuries and reasons for quitting early if they did so. Personal contact information was also collected in the exit survey so the participant could be included in the drawings for incentive gift cards.

In order to control for erroneous data, the surveys captured Internet Protocol (IP) addresses from the accessing computers participants used. There was also a collection of browser types used during access to further confirm if users accessed the surveys from mobile devices. There were no inconsistencies in access point information.

The media necessary to complete the study included various methods to announce the survey. A website (www.hikersurvey.com) was developed to host the survey information and registration process. Survey Monkey was used to develop the surveys and integrate them into the Hiker Survey website. Paper announcements were posted in areas of free Internet access in towns along the AT. QR codes were used to redirect participants to the website from the posted paper announcements. These announcements were set out in the field from March 1, 2012 until November 1, 2012 during the data collection period. The survey website stopped collecting data on November 5, 2012 and the data review process began.

In order to ensure participation of hikers in the survey, there were survey announcements at the start of the trail in Georgia and at the farthest point north in Manchester Center, Vermont. Southbound hikers did not participate even though this study was able to accommodate them as participants as well. Some hikers preferred to thru-hike with alternative itineraries called "Leap Frogging" or "Flip-Flopping" where they started in the middle of the trail, hiked to a terminus, then traveled to the opposite end to hike back to where they started. These hikers were also allowed to participate in the study as the trail surveys do not need to be completed in any particular order. Only one participant reported to have this type of alternative itinerary.

To assist in recruiting participants, study coordinators approached hikers in trail towns asking them to participate in the study. Coordinators provided them either a laptop computer with direct Internet access to the survey website or a paper copy of the survey. Paper surveys included the registration, consent form, pre-hike survey and first trail survey. All data collected was entered into the system while participants received a login and temporary password for future surveys on the website. This method proved the most successful in recruiting as it provided roughly 60% of the participants in the study.

The Appalachian Trail Conservancy (ATC), which is charged for the overall maintenance of the AT, shows that the number of hikers in 2011 was over 1,700 (Appalachian Trail Conservancy, 2011). Based on last year's number and a poll conducted in August, 2011 on WhiteBlaze.net, there was a goal of having 300 participants in the study. Actual participation was only a third of the desired number. However, the population of the study provided ample data for logistic regression analysis of a longitudinal study. The data collected was expected to help answer questions in regards to the effects of pack weight on performance and injuries sustained to long distance hikers. To perform the logistic regression analysis, SPSS version 19 was used.

Results

Logistic Regression Analysis

Logistic regression analysis was conducted to predict completion of a long-distance trail by AT hikers using several predictors. Possible predictors included continuous variables of total body weight (TBW), Body Mass Index (BMI), pack weight (PW), pack load percentage of total body weight (LP), age, and average miles (AvgMiles) per day. The predictors for TBW, BMI, PW and LP all included the baseline or starting values along with the last recorded values, signified as end values in the study. Average miles per day were calculated by participants' provided number of days hiking and total miles achieved. The descriptive statistics of the continuous variables are listed in Table 1.

Table 1

Descriptive Statistics Continuous Predictor Variables

Variables	*M*	*SD*	Minimum	Maximum	*SE*
TBW_start	180.77	40.876	105	364	4.460
TBW_end	165.31	32.070	100	295	3.499
BMI_start	26.18	4.380	17.75	39.98	0.478
BMI_end	24.00	3.481	17.71	33.63	0.380
PW_start	38.25	11.270	18	70	1.129
PW_end	32.49	10.347	14	60	1.031
LP_start	21.76	9.453	9.69	40.91	0.692
LP_end	20.01	5.979	8.11	37.50	0.652
Age	31.31	10.688	18	65	1.166
AvgMiles	13.00	3.016	7.06	19.20	0.329

NOTE: N = 84

Categorical variables used as possible predictors in the analysis were gender, experience, reported injuries, and pack complaints. All categorical variables represented either a value of 0 or 1. Gender values were 0 for female and 1 for male. Experience was transformed from a categorical variable of three levels to a dichotomous variable with two levels; ExpModified. The first level (0) represents hikers with less than 250 miles of total backpacking experience prior to hiking the AT. They were designated with “minimal_experience.” The second level (1) was the “experienced” level with hikers who have backpacked more than 250 miles prior to starting the AT. The Injured variable (values 0 or 1) represented whether a hiker reported injuries to areas of the body that could be most affected by backpacks and/or pack weight. If hikers checked off that they experienced pain or injuries to their shoulders, upper back, lower back or hips at any of the survey points, then they are represented with a value of 1. The categorical variable PackFactor represented hikers who complained of experiencing heavy packs or pain from carrying packs. This information was recorded in addition to the injury question as some hikers may not have been able to directly relate shoulder, back or hip pain to pack weights. The frequencies for the categorical predictors are listed in Table 2.

Table 2

Frequencies of Categorical Predictor Variables

Category Variable	Level	Frequency	Percentage
Gender	Male	62	73.8
	Female	22	26.2
ExpModified	Minimal_Experience	56	66.7
	Experienced	28	33.3
Injured	None	50	59.5
	Injuries_Reported	34	40.5
PackFactor	Pack_no_Factor	66	78.6
	Pack_is_Factor	18	21.4

NOTE: *N*=87

As previously stated, the purpose to the logistic regression analysis was to successfully predict a hiker completing a long-distance trail. The dependent variable for Completed Trail (CompTrail) was dichotomous and set either to 0 for not completing or 1 for completing.

Using SPSS functions for backward, stepwise-regression procedures, a logistic regression model was found that best fit these data, gave the highest prediction success, and best represented the factors needed to predict completing a long distance hike. The backward, stepwise regression produced several models with significant predictors, or variables that contributed the most toward successful prediction. Each non-significant predictor was removed using the Likelihood Ratio Test (*-2LL*) method, which compares the fit of one model to the next, in each backward step. As each least significant predictor was removed, significance increased on favorable predictors. The final model included seven predictors: BMI, PW, LP, AvgMiles, Gender, ExpModified, and Injured. The evaluation of the model showed that three of the predictors were non-significant. They were included in the model as they represented possible latent factors in explained variance and a parsimonious model representing the needs of the study.

Evaluation of the logistic regression model. Using the likelihood ratio test (*-2LL*) to test for significance between the model with predictors and the constant baseline model, the model chi-square for the full model was statistically significant, $\chi^2 = 29.034$, $p < .001$ with $df = 7$. This indicated that the predictors reliably distinguished between those who completed the trail and those that quit early. The Hosmer–Lemeshow (H–L) test for goodness-of-fit ($\chi^2 = 13.358$, with $df = 8$) found there was no statistical significance ($p = .100$) and suggested that data were a good fit for the logistic regression model. Nagelkerke’s R^2 of .419 indicated a 41.9% moderate relationship between predictors and their prediction ability of completing the trail. Prediction success overall was 82.1%. The sensitivity of the model to correctly predict hikers completing the trail was 58.3%. The specificity of the model to predict hikers who did not complete the trail was 91.7%.

According to results in Table 3, the final recorded pack weight (PW_end), the final load percentage values (LP_end), average miles (AvgMiles) and gender were significant predictors in determining if a hiker would complete the trail (CompTrail).

Table 3

Logistic Regression Variables in the Equation (SPSS Output)

Variable	*b*	*S.E.*	*Wald*	*df*	Sig.	Exp(*b*)	95% C.I. for Exp(*b*)	
							Lower	Upper
BMI_end	-.354	.191	3.447	1	.063	.702	.483	1.020
PW_end	.258	.130	3.927	1	.048*	1.294	1.003	1.669
LP_end	-.458	.203	5.096	1	.024*	.632	.425	.941
AvgMiles	.449	.144	9.749	1	.002**	1.566	1.182	2.075
Gender(1)	-2.514	1.051	5.726	1	.017*	.081	.010	.635
ExpModified(1)	.786	.612	1.651	1	.199	2.195	.662	7.281
Injured(1)	.500	.660	.573	1	.449	1.649	.452	6.015
Constant	3.439	5.383	.408	1	.523	31.169	-	-

NOTE: $R^2 = .419$.
*$p< .05$, **$p< .01$

Log odds and odds ratio. In the logistic regression model, predictor coefficients are tested using the Wald chi-square to determine significance of a predictor. Significant chi-square in logistic regression means the variable serves as a good predictor to the outcome variable, CompTrail, as either 1 or 0. Probabilities (*p*) for the outcome variable to be 1 or 0 are calculated using the regression *(b)* coefficient for each predictor variable. In the SPSS output in Table 3, the *b* coefficients are represented in the *b* column. The *b* coefficients, also expressed as log odds, for each predictor represents the slope of the average value of Y for every unit change of X. Prediction for completing the trail is then based on a one-unit change of the predictor variable when controlling for the other variables. The log odds of each independent variable is used to calculate the odds ratio, or likelihood ratio (*LR*) represented in the SPSS output in Table 3 as Exp*(b)*. A one-unit change in the predictor variable will provide a *LR* that the dependent variable will be 1. The logistic regression equation representing the log transformation of *p*, or logit(p), capable of calculating the prediction odds of a hiker completing the trail is shown in Equation 1 below.

$$\text{Logit}(p) = 3.439 + (-.354 * \text{BMI\_end}) + (.258 * \text{PW\_end}) + (-.458 * \text{LP\_end}) + (.449 * \text{AvgMiles}) + (-2.514 * \text{Gender}) + (.784 * \text{ExpModified}) + (.500 * \text{Injured}). \tag{1}$$

This equation can be used to calculate the log odds and the *LR* for prediction of completing the trail. For example if data on a hiker consisted of BMI of 26.5, pack weight of 22 lb, load percentage of 12%, averaged 15 miles a day, gender was male (value is 1), minimal experience (value is 0) and reported an injury (value of 1). The resulting logit(p) equals 1.47. Log odds are confirmed by calculating the odds ratio. For probability (p) is $e^{1.47} / 1 + e^{1.47}$, which equals a .813 probability of completing the trail. The odds ratio that the hiker will complete the trail is .813/.187, or 4.37 times greater than a hiker who was averaging 1 mile less per day, when all the other factors are the same. The natural log of 4.37 is 1.47, confirming the logit(p) calculation.

Poor predictors. In the final model, there were several predictors that were not used in predicting the outcome due to either ineffectiveness or inappropriate use. The continuous variables that were removed from the regression model were age, total body weight (TBW), and the baseline values for BMI (BMI_start), pack weight (PW_start) and load percentage (LP_start). Of the categorical variables, only the variable specifying pack as a limiting factor (PackFactor) was not used.

The age variable showed no indications of being a good predictor as the mean values were nearly a match in each group. The age range of all participants (*N* = 84) was from 18 to 65, *M* = 31. Those that completed the trail (*n* = 24) had a mean age of 32 while the group that did not report finishing the trail (*n* = 60) had a mean age of 31.

Total body weight variables (TBW_start and TBW_end) were not used in the logistic regression model as they showed to have a strong relationship with BMI values. A Pearson product-moment correlation was performed to determine the strength of relationship between BMI and TBW recorded values. The result was a strong, positive correlation between BMI_end and TBW_end, $r = .824$, $N = 84$, $p <.001$. Due to the strong relationship, this analysis only included BMI as it best represents the body and its stature because it is calculated using both body weight and height.

The BMI values that were used in the logistic regression analysis were the final recorded values (BMI_end). This was also true for the pack weight (PW_end) and load percentage (LP_end) values. For each variable type, BMI, PW and LP, there was a strong, positive correlation between the baseline and last recorded values, $r = .903$, $r = .789$, $r = .796$ respectively, $N = 84$, $p < .001$. The rationale for selecting the last recorded values over the baseline values for use in the regression model was due to proper representation of participant information relevant to the study. Baseline values are irrelevant to the analysis of participants completing the trail where changes frequently occur to body weight and pack weight. Using the final recorded values created a better chance for the logistic regression model's ability to predict completing the trail.

The PackFactor variable, which was selected by some hikers to signify that the back pack they were using either hurt or was too heavy, was not used in the analysis. The possible values for this variable were 1 or 0. A total of 18 participants (21% of total, N = 84) selected this option as a limiting factor on their hike. This variable had no significance during the backward stepwise regression and was removed from consideration early in the process.

Good predictors. Variables in the logistic regression model that better contributed to the prediction of the outcome were gender, experience, reported injuries, average miles and the final recorded values for BMI, PW, and LP (see Table 3). Some factors were not regarded as significant predictors such as BMI and injuries reported however during component analysis they loaded with other variables explaining some of all variance. Despite other regression models having fewer variables for successful prediction, the overall success rate for prediction of the selected model was higher and each predictor that is included is dependent on the rest for success in completing the trail. Individually these predictors cannot be used to predict completing the trail. When they are considered as a group of factors, observations confirmed the relevance in the model.

Average miles (AvgMiles) showed significance in results meaning that an increase by one unit to average miles would increase the odds of completing the trail by 1.6 times if all other factors are controlled for (see Table 3). AvgMiles is used as the measure of how hikers were doing in the total mileage for a couple reasons. First, hikers who hiked greater distances had better averages over time. Second, using total miles as a predictor did not create a good-fit for the model as hikers who completed the trail all traveled the same number of miles.

Gender as a predictor was also given significance (*b* = -2.514, $p < .05$) however the odds ratio (*LR* = .081) was drastic between men and women completing the trail. Women were shown to be 12.4 times more likely to complete the trail when all other factors are controlled for. The observed completion rate for men was 27.5% while women had a completion rate of 31.8%. The gender odds ratio may have been influenced by other factors.

The variables PW_end and LP_end show inverse coefficients with completing the trail, *b* = .258 and *b* = -.458 respectively. For every unit increase in load percentage the hiker was .6 times or almost half as likely to complete the trail when the other predictors are controlled for. Pack weight showed an increase by one unit or pound would increase chances of completing the trail while other the predictors are controlled. The inversed coefficients for CompTrail were not expected as the variables have a moderate to strong relationship with each other. This relationship exists since load percentage is calculated using pack weight and total body weight. This inverse relationship may exist since these variables are dependent of the rest of the variables in the logistic regression model. This may suggest that hikers who possibly carried smaller pack weights may have done so at the risk of not carrying enough gear, food or water preventing them from completing the trail.

Both variables were used in the regression model despite their relationship for two reasons. The first reason is because they are different when it is considered that LP is calculated from both PW and TBW. The backpacking industry usually uses pack weight to categorize hikers, such as “ultralight” or “lightweight” and then develops backpacks for each category. Meanwhile studies that have been performed in load carriage use LP of total body weight. The second reason is because the PW_end variable had a stronger relationship with both total miles hiked (TotalMiles) and average miles per day (AvgMiles) than the LP_end variable. Finally, with the goal of finding safer pack weight limits for backpackers, merging the results of PW and LP analysis helped in finding pack load thresholds that could reduce injuries and increase success rates. Hence, both variables needed to be included in the logistic regression model.

Performance of the logistic regression model was tested for internal validity to ensure the same results could be repeated. To test repeatability a smaller sample of the same data set was used. A random 20 participants were selected from the full data set (N = 84) and were assessed using the logistic regression equation or logit(p). The group selected had 4 participants who completed the trail and 16 that did not report finishing. The probabilities that hikers would either be 0 or 1 for completing the trail were 100% accurate. The 4 hikers who actually completed the trail all had shown probabilities greater than .5 while the remaining 16 participants were below the .5 mark.

The external validity of the logistic regression model can also be tested with a related but slightly different population. This would require the study to be conducted again on the AT with hikers going the same distance, roughly in the same amount of time and with the same procedures used for this study. However, there is no current plan to conduct another study.

With the test of internal validity no particular relationship was evident in pack weights as one participant that completed the trail carried a 40 lb pack while others who carried less did not have a positive probability calculated. This may suggest that there are other relationships or factors that influence the outcome along with pack weight. To better understand the relationship of these predictors and other influences, exploratory factor analysis (EFA) was performed on the variables used in the model.

Factor Analysis

To explain the correlations of the predictor variables, exploratory factor analysis was conducted to account for variance in the model that cannot be explained through logistic regression. The analysis included either variables from the model or other high correlating variables. Strong correlations of some variables dictated the inclusion of predictors to avoid multicollinearity within the analysis.

Correlations. Factor analysis included TotalMiles since it had a strong relationship with the dichotomous dependent variable for completing the trail (CompTrail), $r = .849$, $N = 84$, $p < .001$. TotalMiles, a continuous variable with values ranging from 0 to 2184, was determined best for use in the analysis. This created a numerical scale that represented the status of the hiker, however it was not found to be useful in the logistic regression model as a predictor.

Predictors that had strong correlations among their baseline and final recorded values were BMI, pack weight and load percentage. BMI_start and BMI_end had a strong positive relationship in a Pearson product-moment correlation test, $r = .903$, $N = 84$, $p < .001$. PW_start and PW_end also had a strong relationship with $r = .789$, $N = 84$, $p < .001$. Finally, the baseline and final values for load percentage, LP_start and LP_end, showed a strong relationship as well, $r = .796$, $N = 84$, $p < .001$. In addition to these relationships, pack weight and load percentage showed strong relationships between them. The baseline values of pack weight and load percentage had a correlation of $r = .673$, $N = 84$, $p < .001$. The final recorded values for both had a correlation of $r = .774$, $N = 84$, $p < .001$. The observed high correlations for these variables prompted removal of variables to avoid multicollinearity. BMI baseline (BMI_start) was removed for analysis in favor of the last recorded value (BMI_end). All PW and LP variables were used to create composite variables for Pack Load Score.

Pack Load Score. The creation of Pack Load Score (PLS) was needed to prevent multicollinearity issues during factor analysis. To create the PLS each participant was scored on their PW and LP for both baseline and last recorded values. The baseline scores for both were then added together to create the PLS baseline variable (PLS_start). The same procedure was used for the last recorded scores to create the PLS last recorded variable (PLS_end). The PLS variables were then used in factor analysis. Scores and criteria for each variable are shown in Table 4.

Table 4

Pack Weight and Load Percentage Scoring Descriptions

Variable to Score	Score Criteria	Score
Pack weight	Less than or equal to 10 lb	0
	Over 10 lb and less than or equal to 20 lb	1
	Over 20 lb and less than or equal to 30 lb	2
	Over 30 lb and less than or equal to 40 lb	3
	Over 40 lb	4
Load %	Less than or equal to 10%	0
	Over 10% and less than or equal to 20%	1
	Over 20% and less than or equal to 30%	2
	Over 30%	3

NOTE: Pack Load Score is the combined scores of pack weight and load percentage.

Analysis. Components were extracted using principle component analysis in SPSS. It was determined that three factors were to be retained. This was determined by the comparison of eigenvalues from SPSS principle component analysis and those randomly generated from a correlation matrix using the Monte Carlo PCA for Parallel Analysis software (Watkins, 2000). Varimax orthogonal rotation was used to determine the loading of variables on the components.

Three components explained 70.8% of the all variance in the variables including error variance (SAS Institute Inc., 2005). While the variance explained is not restricted to common variance among the variables, Principle Component Analysis (PCA) yielded similar results to the EFA (Fabrigar, Wegener, MacCallum, & Strahan, 1999) that was also performed. EFA resulted with the first two primary factors explaining a total of 62.8% of common variance.

The results of PCA show Factor 1, Pack Load Conditions, had an initial eigenvalue of 2.113 and a rotated eigenvalue of 1.878 accounting for 26.8% of all variance. Factor 2, Hiking Rates, had an initial eigenvalue of 1.574 and a rotated eigenvalue of 1.763 accounting for 25.2% of all variance. Factor 3, Gender Weight Differences, had an initial eigenvalue of 1.250 and a rotated eigenvalue of 1.317 accounting for 18.8% of total variance. The modified experience variable (ExpModified) was removed for a low communal value. Table 5 shows the rotated loading solution generated from the analysis.

Table 5

Pattern/Structure Coefficients from PCA with Varimax Rotation

	Component		
Variable	1 (Pack Load Cond)	2 (Hiking Rates)	3 (Gender Wt Diff)
PLS_start	**.910**	-.028	.003
PLS_end	**.883**	-.215	-.012
AvgMiles	-.162	**.845**	.073
TotalMiles	-.008	**.815**	-.014
Gender	-.011	.059	**.824**
BMI_end	-.039	**-.541**	**.624**
Injured	**.491**	.202	**.493**

NOTE: Factor loading > .4 are in boldface.

The PCA showed that the Pack Load Scores for PW/LP baseline and final recorded values grouped together with high loading. Injured has a moderate load on that same component called Pack Load Conditions. Hiking Rates had a high loading of AvgMiles and TotalMiles, variables that measure the distance status of hikers, one daily and the other in terms of completion. The final BMI variable also slightly loaded to that component. Gender Weight Differences describes the high loading of Gender and BMI_end in the same factor. The injured variable also loaded to that component.

For parsimony analysis, retaining the fewest factors to explain variance, follow-up EFA was conducted using the Principle Axis Analysis method in SPSS with Varimax rotation. The follow-up EFA required the additional removal of the Gender, Injured, and BMI_end variables for low communal values. The results showed Factor 1, Pack Load Conditions, had an initial eigenvalue of 1.943 and a rotated eigenvalue of 1.471 accounting for 36.8% of common variance among the variables. Factor 2, Hiking Rates, had an initial eigenvalue of 1.312 and a rotated eigenvalue of 1.039 accounting for 26% of common variance. Some of the previously removed variables were a part of the third factor that was extracted in PCA. Hence only two factors were extracted and Gender Weight Differences were not accounted for in EFA. Table 6 shows the rotated loading solution generated from the analysis.

Table 6

Pattern/Structure Coefficients from EFA with Varimax Rotation

	Factors	
Variable	1 (Pack Load Cond)	2 (Hiking Rate)
PLS_start	**.854**	-.006
PLS_end	**.850**	-.213
AvgMiles	-.138	**.705**
TotalMiles	-.032	**.705**

NOTE: Factor loading > .4 are in boldface.

The factor analysis confirmed the primary factors that explained common variance in the variables pertain to the pack weights carried and number of miles hiked per day.

Repeated Measures Analysis

Studying the effects of pack weight on completing a long-distance hiking trail, such as the AT, and the ability to predict completing the trail, required an analysis of the group that reported successfully finishing the trail. By using repeated measures Analysis of Variance (ANOVA), changes that occurred to participants over the course of their hike became apparent. The analysis included BMI, PW, LP, and AvgMiles for the group of hikers that completed the trail (N = 24). BMI, PW, LP and AvgMiles descriptive means for each survey are listed in Table 7.

Table 7

Descriptive Statistics, Repeated Measures of Completed Trail

Predictor	Survey Point	*M*	*SD*
BMI	Baseline	25.338	3.6803
	Survey 1	24.050	3.5375
	Survey 2	23.683	3.3182
	Survey 3	23.167	3.0660
	Survey 4	22.817	3.1938
PW	Baseline	35.917	9.4270
	Survey 1	31.125	8.9210
	Survey 2	30.250	10.3050
	Survey 3	28.125	9.5660
	Survey 4	28.750	10.0360
LP	Baseline	20.743	5.5935
	Survey 1	18.942	5.6849
	Survey 2	18.579	6.0576
	Survey 3	17.527	5.4209
	Survey 4	18.174	5.6395
AvgMiles	Survey 1	13.629	2.4414
	Survey 2	14.508	2.3895
	Survey 3	15.529	2.7898
	Survey 4	15.142	2.1555

NOTE: N = 24

Body Mass Index. During BMI analysis, Mauchly's test of sphericity showed sphericity was violated ($\chi^{2} =$ 58.036, with $df = 9$, $p < .001$). A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean BMI differed significantly between the surveys ($F(1.801, 41.433) = 17.874$, $p < .001$). Post-hoc tests using the Bonferroni correction showed a major reduction in BMI from the start of the trail to all survey points in the study making the difference between baseline and each survey statistically significant (see Table 7 for mean values and Table 8 for mean differences). When reviewing the decreasing BMI values per survey, mean BMI values decreased the most from baseline to the first survey (25.34 ± 3.68 *vs.* 24.05 ± 3.58, respectively, with *M* difference of 1.29, $p = .002$) suggesting hikers may have worked harder during that period. By the fourth survey mean BMI values (22.82 ± 3.19) were at their lowest and decreased by 1.23 since the first survey, almost doubling the mean difference from baseline (2.52). Figure 5 illustrates the mean BMI values throughout the study.

Table 8

Body Mass Index (BMI) Pairwise Comparisons

(I) Surveys	(J) Surveys	*M* Diff (I-J)	*SE*	Sig.
Baseline	1	1.288**	.289	.002
	2	1.655**	.377	.002
	3	2.172***	.415	.000
	4	2.522***	.490	.000
1	Baseline	-1.288**	.289	.002
	2	.367	.252	1.000
	3	.883	.346	.178
	4	1.233*	.370	.029
2	Baseline	-1.655**	.377	.002
	1	-.367	.252	1.000
	3	.517	.173	.066
	4	.867**	.225	.008
3	Baseline	-2.172***	.415	.000
	1	-.883	.346	.178
	2	-.517	.173	.066
	4	.350	.167	.477
4	Baseline	-2.522***	.490	.000
	1	-1.233*	.370	.029
	2	-.867**	.225	.008
	3	-.350	.167	.477

*p <.05, **p < .01, ***p < .001

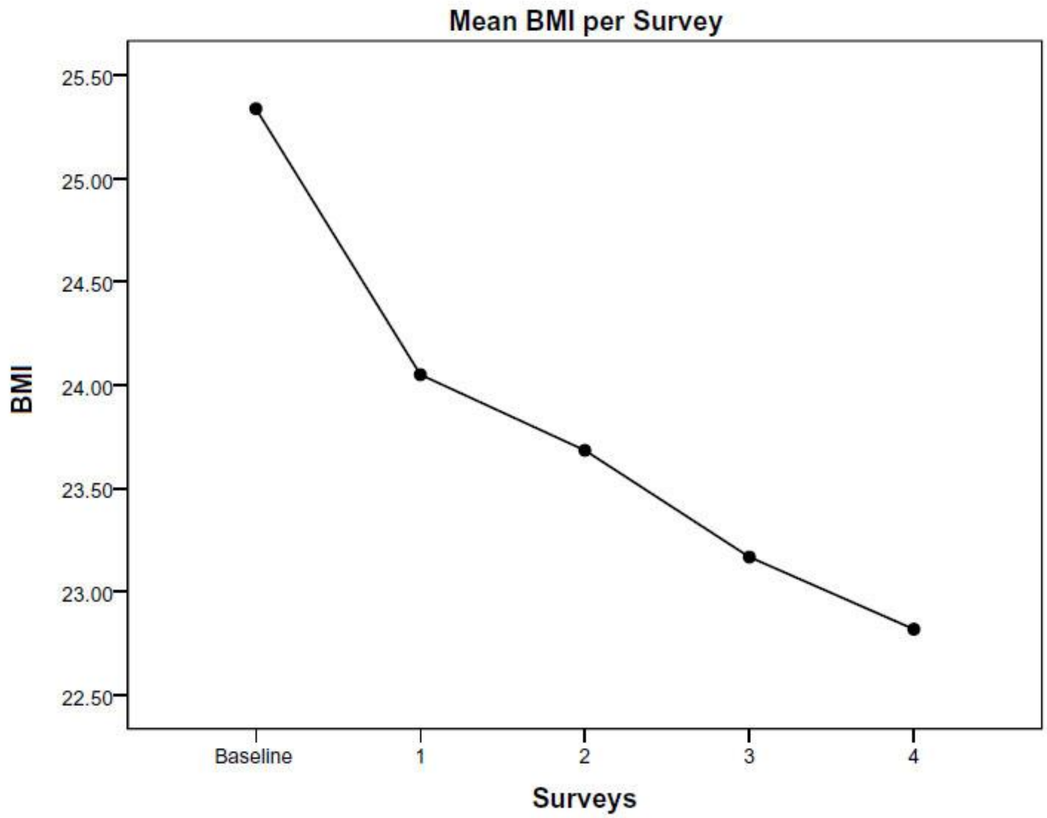

Figure 5. Mean BMI for hikers who completed the trail. Mean BMI values illustrated in this chart show the significant decreases in BMI throughout the study (*N* = 24). The baseline measures for BMI (25.34 ± 3.68) are much higher than at the rest of the survey points indicating significant weight loss by participants early in the study.

Pack weight and load percentage. A repeated measures ANOVA was performed on pack weight (PW) for the group that completed the trail (*N* = 24). Mauchly's test of sphericity showed sphericity was violated ($\chi^{2\,=}$ 27.045, with *df* = 9, *p* = .001). The Greenhouse-Geisser correction showed a significant difference in PW between the surveys (*F*(2.542, 58.055) = 16.509, *p* < .001). Post-hoc tests using Bonferroni correction revealed that recorded pack weights were significantly greater at baseline than any other survey. The largest decrease in PW occurred between baseline and the first survey (35.92 ± 9.43 *vs.*31.13 ± 8.92, respectively with mean difference of 4.79, $p < .01$) suggesting that participants discovered early in their hike what equipment was essential and what was unnecessary. Figure 6 illustrates the pack weight changes across the survey for the group that completed the trail.

For the load percentage (LP), Mauchly's test of sphericity showed sphericity was violated ($\chi^{2\,=}$ 43.586, with $df = 9$, $p < .001$). The Greenhouse-Geisser correction revealed a significant difference in the load percentages carried by hikers between the surveys ($F(2.081, 47.861) = 5.740$, $p < .01$). Post hoc tests using Bonferroni correction shows a significant difference ($p < .05$) in LP between baseline and the first survey (20.743 ± 5.59 *vs.* 18.942 ± 5.68, respectively). This drop in LP in the first survey was unexpected as hikers lost a significant amount of body weight at the same time they dropped pack weight. This created the expectation that LP would not change or only change slightly since it is calculated using both body weight and pack weight. The conclusion is that hikers that completed the trail lost more pack weight in the beginning of the trail when it is considered as part of the pack weight / body weight ratio. This loss of pack weight is reflected in the gear they carried for basic needs on the trail and the importance of carrying less. Figure 7 further illustrates that the loss of pack weight affected the load percentage in the same way when compared to Figure 6. Final recorded values for PW and LP had a correlation of $r = .774$, $N = 84$, $p < .001$. Another noticeable trend in both PW and LP is the slight increase in mean values at survey 4 (see Figures 6 and 7). The rise in PW and LP in the fourth survey was expected as hikers added cold weather gear to their packs for the mountainous terrain in New Hampshire and Maine.

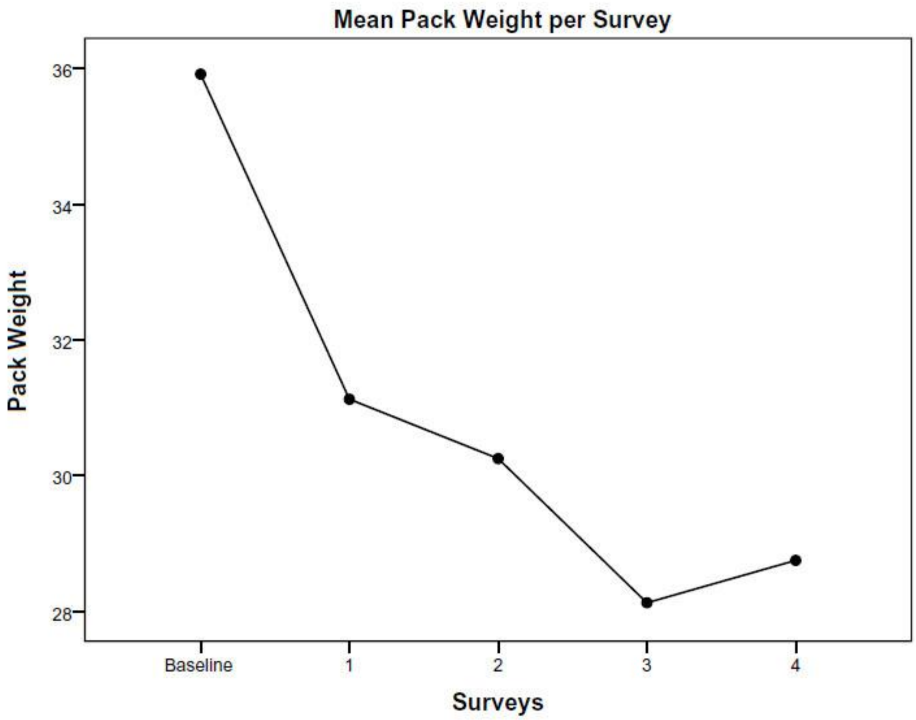

Figure 6. Mean PW for hikers who completed the trail. Mean PW is shown here across the study with a significantly higher mean PW at baseline. The baseline measures for PW (35.92 ± 9.43) are significantly different from the first survey as the hikers dropped pack weights the most in the beginning of the hike.

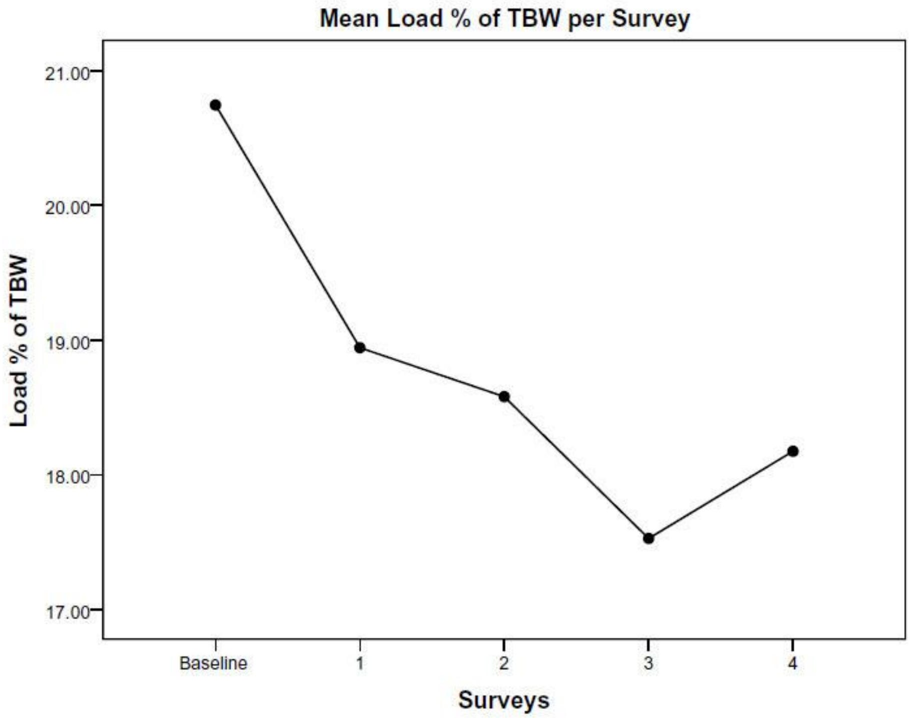

Figure 7. Mean LP for hikers who completed the trail. Mean LP is shown here across the study illustrating the significant difference of LP values starting at baseline. Just like PW the baseline measures for LP (20.743 ± 5.59) are significantly different from the first survey. The rise in LP in Survey 4 (18.174 ± 5.64) accounts for hikers adding cold weather gear back to their packs.

Average miles. A repeated measures ANOVA determined that the mean of the calculated average miles hiked per day (AvgMiles) was significantly different when viewed at each survey point ($F(3, 69) = 16.528$, $p < .001$). Post hoc tests revealed that AvgMiles was much lower in the first survey (13.629 ± 2.44) when compared to the third and fourth surveys (15.529 ± 2.79, $p < .001$ and 15.142 ± 2.16, $p < .005$, respectively). An additional statistical difference was found between the second survey and the third survey (14.508 ± 2.39*vs.*15.529 ± 2.79, $p < .05$). The sample of hikers that completed the trail had an increase in average miles per day between the first, second and third surveys as pack loads became lighter. The largest increase in average miles occurred between the second and third surveys, coinciding with hikers carrying the least amount of weight. They also had a slight decrease in average miles per day at the same time they began carrying cold weather gear after the third survey (see Figure 8).

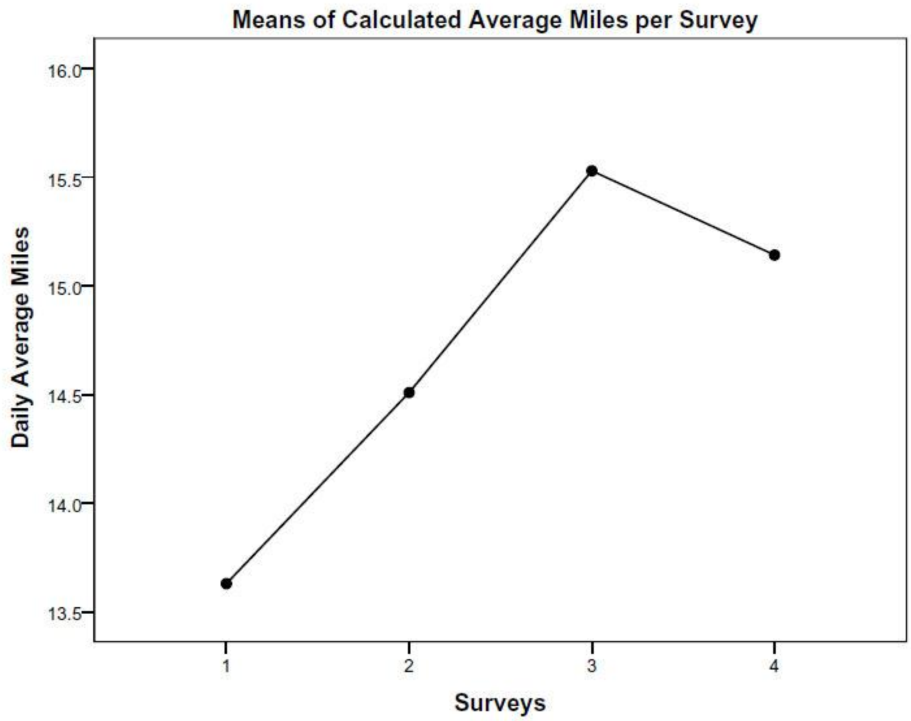

Figure 8. Average miles per day for hikers who completed the trail. Estimated marginal means of average miles per day shows a significant difference in values ($p < .005$) between baseline and surveys 3 and 4. There is also a difference between surveys 2 and 3($p < .05$). Note that after survey 3 the AvgMiles slightly decreases in response to hikers carrying more pack weight by adding cold weather gear to their packs.

A Pearson product-moment correlation performed on AvgMiles and PW_end for all participants showed a statistically significant medium, negative correlation between AvgMiles and PW_end (r = -.399, N = 84, p < .001) causing average miles per day to decrease as pack weight increases (see Figure 9). A statistically significant small negative relationship was also found between AvgMiles and LP_end, r = -.219, N = 84, p < .05; as load percentages increase the average miles per day decrease (see Figure 10). This was expected as load percentage (LP) variables are calculated using pack weight and total body weight.

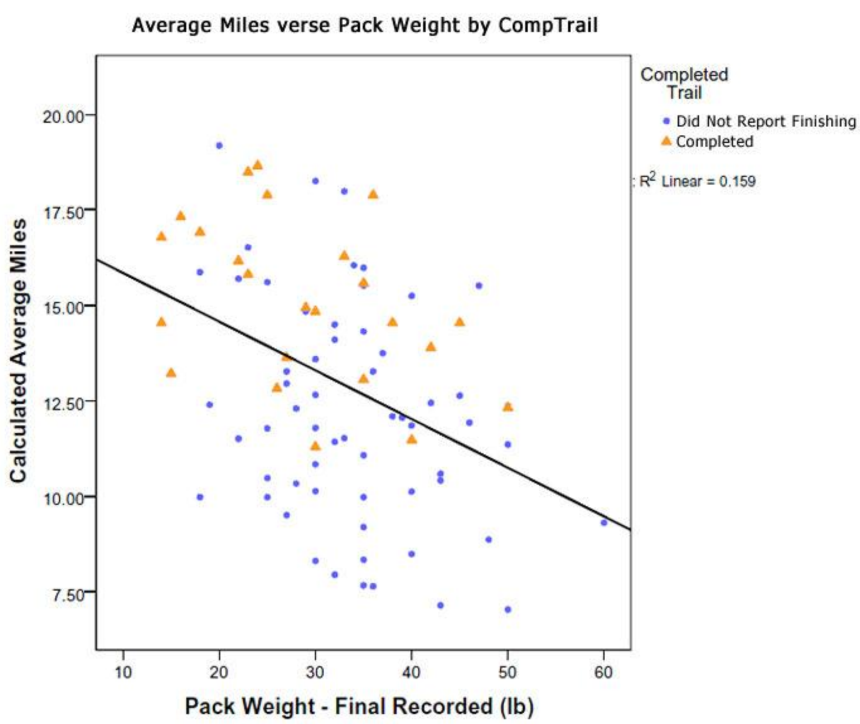

Figure 9. The relationship between AvgMiles and PW. The relationship between AvgMiles and PW shows a negative trend, as an increase in pack weight occurs, a decrease in average miles per day results. Those that completed the trail maintained higher average miles per day than the group that did not report finishing.

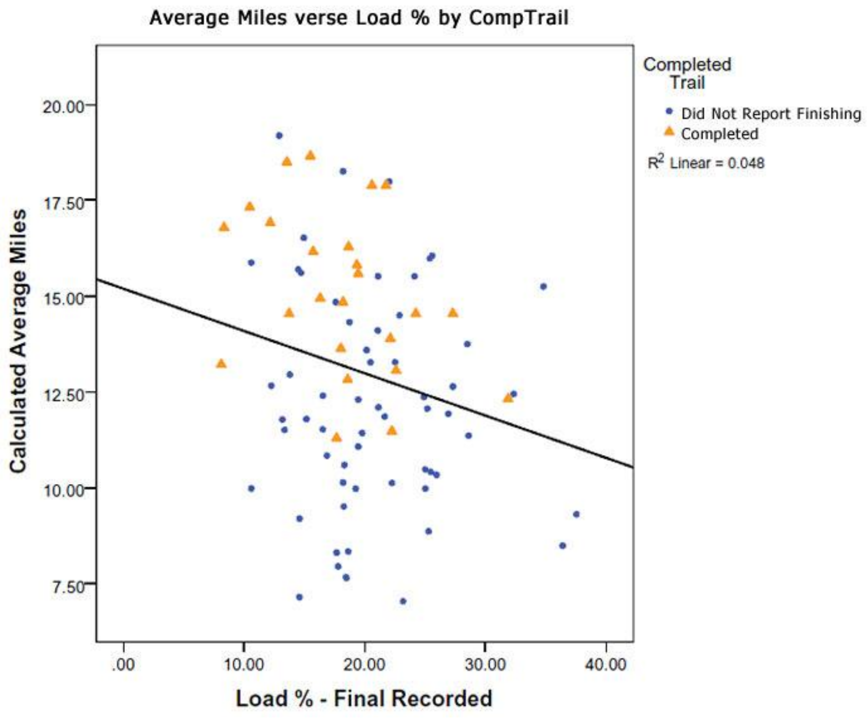

Figure 10. The relationship between AvgMiles and LP. A relationship also exists between AvgMiles and LP revealing a trend that an increase in load percentage will result in a decrease in average miles.

Body weight in this study was represented using BMI. The final BMI values show a significant medium negative relationship with AvgMiles (r = -.358, N = 84, p < .01); as BMI values increased the AvgMiles per day decreased.

Since both body weight and pack weight are subject to change during long distance hiking, a conclusion can be made that AvgMiles per day are reflective of the changes in body weight, pack weight, and load percentages for all hikers. Thus BMI, PW, LP and AvgMiles are interdependent and must all be considered for predicting completing a long distance hiking trail.

Load Percentage Categories

For the purposes of testing the secondary and tertiary hypotheses of this study, LP categories had to be created to determine if hikers were affected in number of miles hiked according to the LP they carried. The categories represented hikers by the load percentage of total body weight carried divided into four levels: 10% and under, 10% to 20%, 20% to 30%, and over 30%. There was not much difference between the groups, other than a trend of moving into lower parts of the scales with some crossover into other groups as hiker changed pack weight and lost body weight during the hike (see Figures 11 and 12).

Figure 11. Hikers charted by LP at baseline. This chart illustrates the LP grouping based on total body weight and the pack weight hikers carried from the start of the trail.

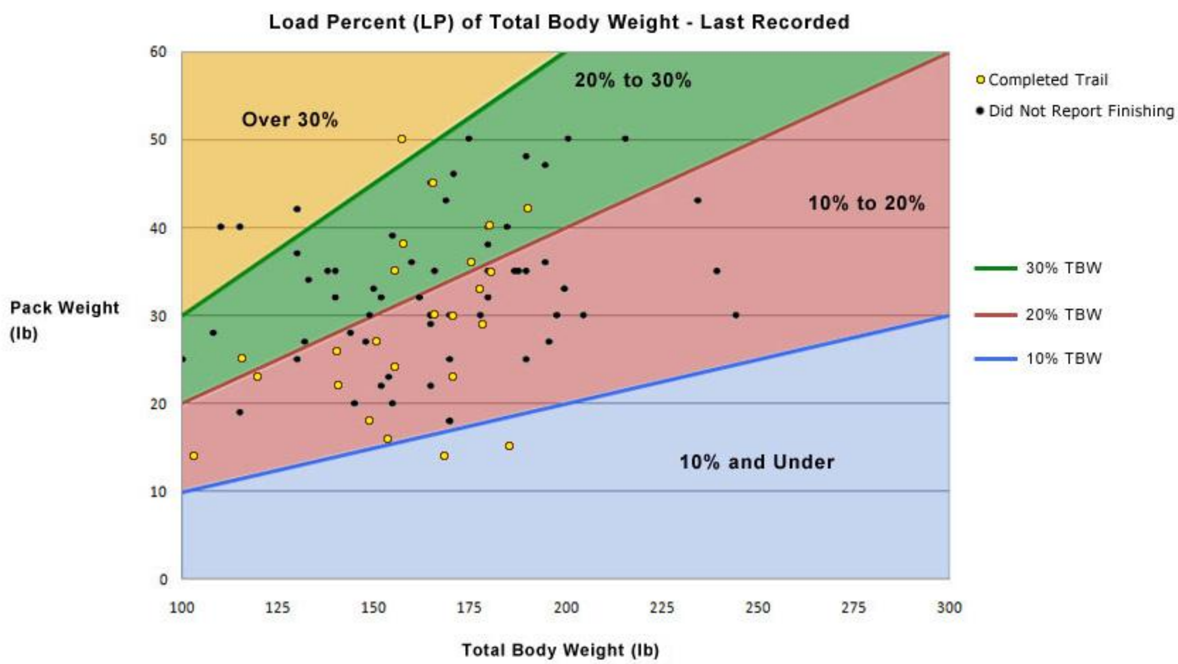

Figure 12. Hikers charted by LP at their last recorded PW. This chart illustrates the LP grouping based on the last recorded values for the total body weight and pack weight hikers carried.

Using Spearman's rank order correlation the relationship of both the LP category variables as baseline and last recorded values were tested with the null hypothesis that there is no relationship between the LP categories and AvgMiles ($H1_0$: There is no association between the LP_Cat_start and AvgMiles; $H2_0$: There is no association between the LP_Cat_end and AvgMiles). Neither the LP categories at baseline (LP_Cat_start) nor last recorded (LP_Cat_end) values showed any association with AvgMiles ($r_s(85)$ = .005, p= .962 and $r_s(85)$ = -.081, p = .456, respectively). Thus the null hypothesis was accepted for both. Since the related continuous variable LP_end was found to be a good predictor of completing the trail, a non-parametric test was run on only the LP categories as last recorded (LP_Cat_end) for effects on AvgMiles. A Kruskal Wallis test revealed no significant effect of LP_Cat_end on AvgMiles($\chi^2(3)$= 1.988, p= .575) as AvgMiles are evenly distributed across the categories.

Testing continued to see if a relationship existed between the LP categories and completing the trail (CompTrail). Using Spearman's rank order correlation the relationship of both the LP category variables was tested with the null hypothesis that there is no relationship between the LP categories and CompTrail ($H1_0$: There is no association between the LP_Cat_start and CompTrail; $H2_0$: There is no association between the LP_Cat_end and CompTrail). Neither the LP categories at baseline (LP_Cat_start) or last recorded (LP_Cat_end) values showed any association with CompTrail ($r_s(85)$ = .008, p= .942 and $r_s(85)$ = -.152, p = .159, respectively). Thus the null hypothesis was accepted for both. Since TotalMiles had a high correlation with CompTrail ($r_s(85)$ = .783, p < .001), a non-parametric test was run on LP_Cat_end for effects on TotalMiles. A Kruskal Wallis test revealed a no significant effect of LP_Cat_end on TotalMiles ($\chi^2(3)$= 3.426, p= .331) as TotalMiles were evenly distributed across the categories. A possible conclusion to the groups not having any significance may have been due to a lack of participants in the lower and upper most groups, indicating that the designs of categories based on load percentages were ineffective.

Hypotheses Results

The primary hypothesis of this study was that hikers would be negatively affected in the number of miles hiked (Total Miles) as pack weight increases (H_{Miles}: μ_1 decreases as μ_2 increases). Logistic regression analysis revealed pack weight and load percentage to be good predictors for the dependent variable for completing the trail (CompTrail) or total miles. In addition, data collected from participants show support of average miles being negatively affected by load percentage and pack weight, as their values increased, average miles per day decreased. AvgMiles was also a significant predictor in CompTrail and had a high loading with TotalMiles in the factor Hiking Rates, suggesting a strong relationship between them. The resulting analysis would suggest then that pack weights did affect both total miles hiked and average miles per day. Accordingly, results did support the primary hypothesis that hikers are negatively affected in number of miles hiked as pack weight increases.

Two secondary hypotheses were also tested. First, it was predicted there would be a significant difference between the LP category groups based on the number of miles hiked ($H_{LP\text{-}Group\text{-}Miles}$: $\mu_{Group1} \neq \mu_{Group2} \neq \mu_{Group3} \neq \mu_{Group4}$). The LP categories were created to show a grouping of participants with similar loads based on their body weight and pack weight. The LP categories showed no association with AvgMiles and AvgMiles was evenly distributed across the categories. As a result of these tests, this hypothesis was not supported as there was no significant difference between the LP groups on number of miles hiked.

Second, it was predicted there would be a significant difference between the LP groups and completing the trail ($H_{LP\text{-}Group\text{-}Complete}$: $\mu_{Group1} \neq \mu_{Group2} \neq \mu_{Group3} \neq \mu_{Group4}$). The LP categories showed no association with CompTrail and TotalMiles was evenly distributed across the categories. As a result of these tests, this hypothesis was also not supported as there was no significant difference between the LP groups and being able to complete the trail.

Additional Analyses

The purpose of this study was to understand the effects of pack weight under long-term load carriage conditions. Additional analyses were conducted to help in illustrating the pack weight differences between hikers who completed the trail and those that did not report finishing. The analyses also included comparisons between hikers who reported injuries and those that did not in relation to their pack load conditions.

Further breakdowns were needed to satisfy additional goals of this study as well. One such goal was to identify possible pack weight limits for long-distance hiking to help in successfully completing a hike and to avoid injuries. This was accomplished by assessing trends found in pack weights carried by hikers under various criteria. These analyses also drove the development of an index of pack loads that can be used to describe suggested pack limits.

Prediction and Factors

To determine if a hiker could complete a long distance hiking trail, a logistic regression model was created based on the prediction ability of factors associated with long-term load carriage. The model had a prediction success rate of 82.1%. BMI, pack weight, load percentage of the pack, average miles per day, hiker experience, reported injuries and gender were all a part of the prediction process. The most significant predictors were pack weights, load percentages, average miles and gender. These variables, along with other predictors, were part of latent factors that helped to explain 70% of the variance in the model.

The significance of predictive factors appears to be supported when the descriptive means are compared between the two groups of the dependent variable, CompTrail. The means for each group were compared from two snapshot points, one from baseline and the second from the final recorded values. Data tables for final recorded values were compiled from the last survey of each participant. A comparison of mean values for the significant predictors revealed that the group that reported completion (RC, *n* = 24) carried less weight and hiked more miles per day than those who did not report finishing (DNRF, *n* = 60, see Table 9). However, an analysis of the mean values at each survey point was also conducted to identify trends for each of the quantitative predictors.

Table 9

Means Comparisons by CompTrail

Completed Trail	BMI	PW (lb)	LP	AvgMiles	*n*
Did Not Report Finishing					
Baseline	26.512	39.18	22.16	-	60
End	24.458	33.98	20.75	12.146	60
Reported Completion					
Baseline	25.338	35.92	20.74	-	24
End	22.820	28.75	18.17	15.138	24

Body Mass Index. BMI was not found to be a significant predictor by itself. This is due to hikers experiencing similar reductions in body weight as they continued on the trail (see Figure 13). Data on BMI suggests that hikers were losing weight at nearly the same rates across the study, except from baseline to the first survey where those who did not report finishing the trail had lost more weight. This difference did not seem to be of value since all the same hikers were present for the first survey where *M* BMI differed by 0.66 between the groups.

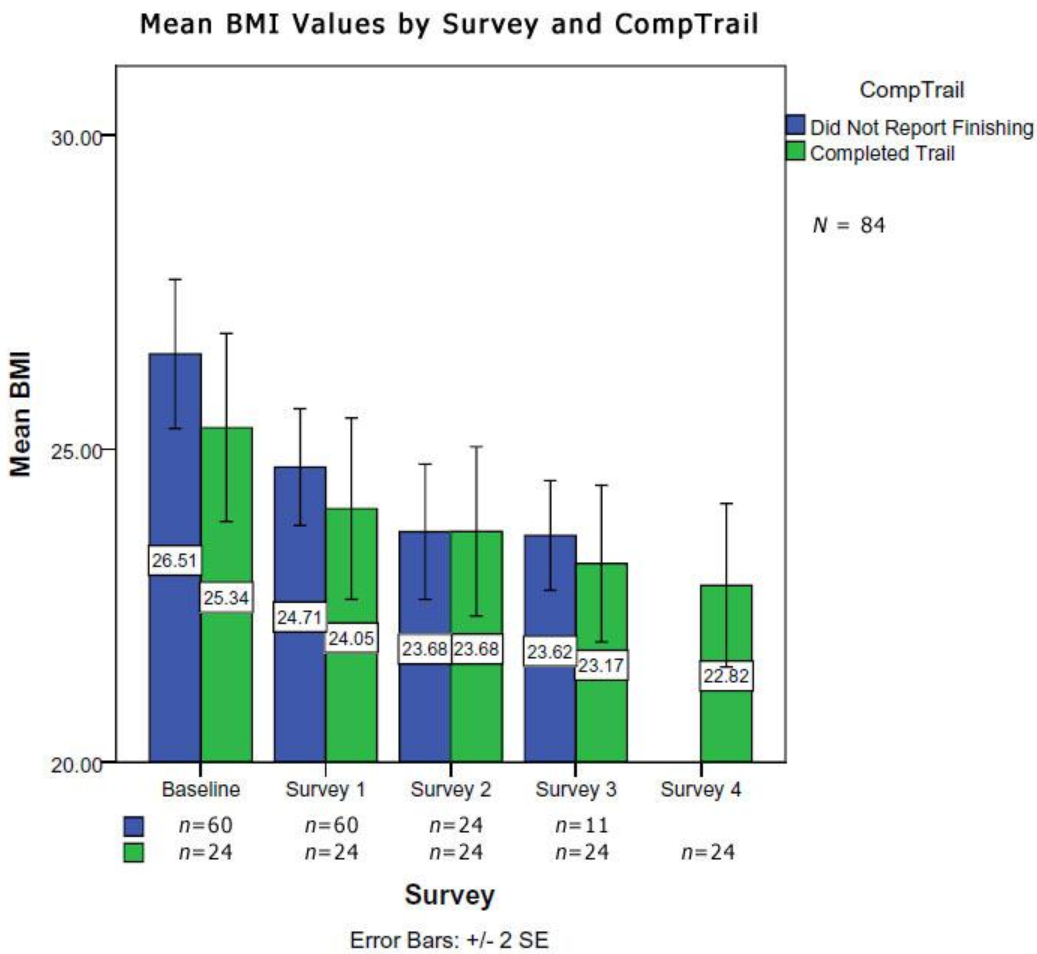

Figure 13. Mean BMI bar graph by Survey and CompTrail. The means for Body Mass Index values per survey dropped for participants the longer they continued hiking. With the exception of the mean values at baseline, hikers BMI values were relatively close throughout the study, suggesting that the activity had the same effect on all hikers.

Pack weight and load percentage. PW and LP values at baseline were higher for the DNRF group than the RC group. Pack weight is considered the base weight of the pack plus the maximum amount of food and water carried after a resupply. The LP is the pack weight as a load percentage of total body weight. The RC group had a significant drop in PW (31.12 ± 8.12) and thus LP (18.942 ± 5.68) before reaching the first survey point. This drop in PW and LP from the baseline survey was the largest change in pack weight when comparing the means of the first survey to the rest of the surveys, PW *M* difference of -4.8 and LP *M* difference of -1.801. The final recorded values for PW and BMI had a small correlation (r = .291, p < .05), suggesting that the heavier the hiker was, the more pack weight they carried. LP had a small negative correlation with BMI (r = -.259, p < .05) meaning that as a hiker lost body mass while their pack weight did not change, then the LP increased. This negative correlation with BMI along with the consistent drop in LP during the study would indicate that hikers in the RC group had significantly reduced their pack weights during their hike to coincide with dropping BMI rates. Data also suggests that hikers in the DNRF group made smaller adjustments in pack weights but not enough to lower their LP values (see Figures 14 and 15).

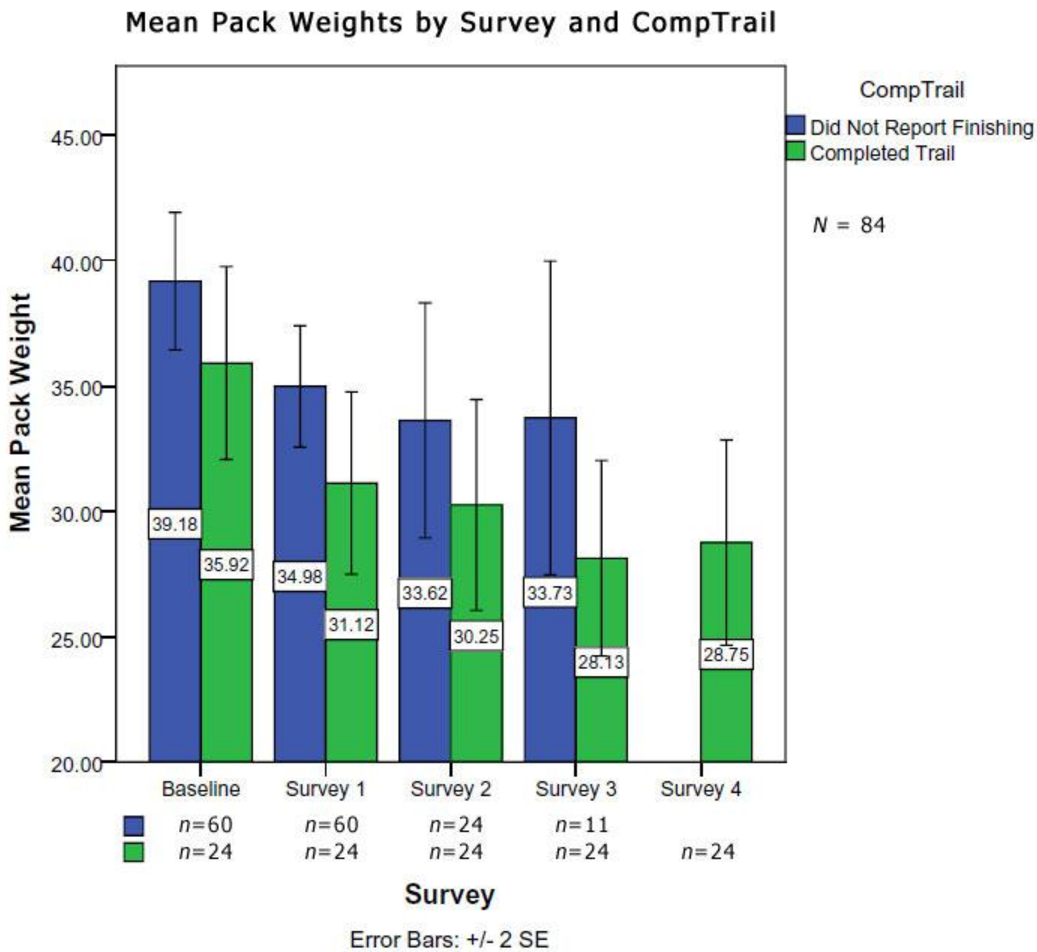

Figure 14. Mean PW bar graph by Survey and CompTrail. The means of pack weights for those that completed the trail had a steady decline until after the third survey point, where they changed to cold weather gear. Those that did not report finishing the trail also had a steady decrease until after the second survey point. Pack weight means for that group, however, never matched those that completed the trail, who were always much lower.

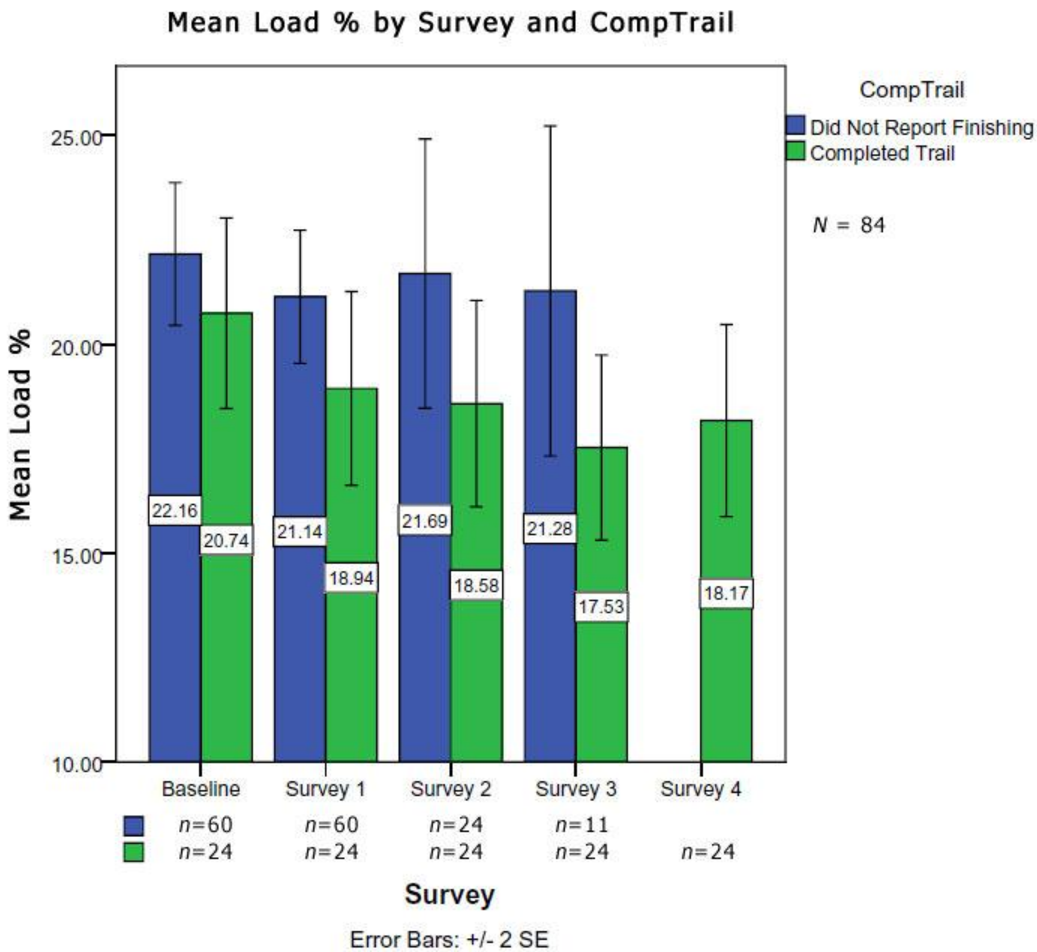

Figure 15. Mean LP bar graph by Survey and CompTrail. The means of load percentages for those that completed the trail also had a steady decline until after the third survey point, where they changed to colder weather gear. Those that did not finish the trail had not made significant adjustments to pack weights while their body mass decreased.

A conclusion can be made that the DNRF group continued carrying pack loads that were not adjusted for the losses in body weight. With a small negative correlation between LP and AvgMiles (r = -.219, n = 84, p < .05) and a moderate to strong correlation with AvgMiles and

TotalMiles (*r* = .502, *n* = 84, *p* < .001), a conclusion can be that the higher LP values may affect hikers in two ways, lower average miles per day (see Figure 16) and possible attrition from the trail.

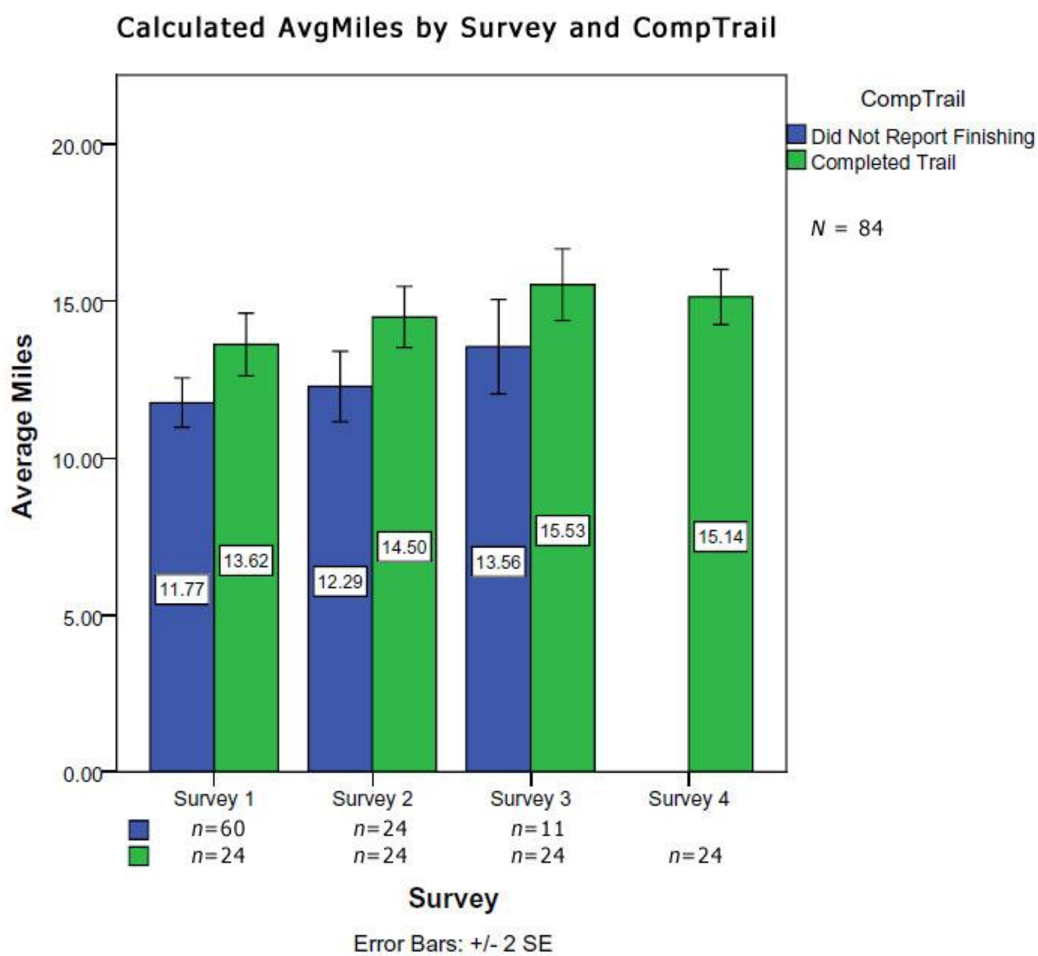

Figure 16. Calculated AvgMiles bar graph by Survey and CompTrail. The average miles per day increase with each survey. The group that completed the trail however consistently had higher averages suggesting that hiking more miles a day may contribute to being able to complete the trail.

Average miles. In the results of the logistic regression, AvgMiles was shown to be a significant predictor for completing the trail. Hikers who increase their average miles per day by one mile increase their chances of completing the trail by 1.6 times when all other factors are controlled for. In observed data, AvgMiles revealed that hikers who completed the trail generally had more daily miles completed per day than the DNRF group. As previously stated, AvgMiles had a small negative relationship with LP and an ever stronger negative relationship with PW (r = -.399, n = 84, p< .001). When these relationships are considered, there is sufficient evidence to suggest that these relationships are interdependent. This means that there was no possibility to use AvgMiles as a lone predictor.

It is important to note that AvgMiles was not expected to be a significant predictor in being able to complete the trail. Prior to the data analysis there were aspects of long distance hiking that were expected to have an effect on average miles per day based on researcher observations. Those aspects were fitness of hikers, terrain difficulty, and willingness to enjoy the hike at a slower pace. Researcher observations during data analysis had precluded these variables from possible predictors in completing the trail as they each had limited ability in affecting average miles.

Fitness of participants was ruled out since most hikers lost significant weight and become accustomed to hiking long days over time. Data supporting this rationale showed that participants became fit after the first quarter or 500 miles of the trail with BMI values falling into normal levels (see Figure 13, Survey 1 BMI levels).

At the end of data collection, terrain difficulty was expected to have an effect on average daily miles. It was first observed that hikers were putting on more miles per day while hiking through easier terrain (see Figure 17). However, later observations also noted that hikers reached the most difficult part of the trail after the third survey and only had a slight decrease in average miles per day. The suggestion that terrain did not affect the average miles per day is further evident when comparing the AvgMiles recorded after each section. For the hikers who completed the trail, earlier sections of the trail were much easier than the final section and mean AvgMiles in the final section was still greater than the first two surveys (see Figure 16). An additional indication is that more hikers met with attrition in easier areas of the trail. It should also be noted that not a single participant offered terrain as a limiting factor to their hike. This study showed no supporting data to suggest there was a relationship between terrain and average miles.

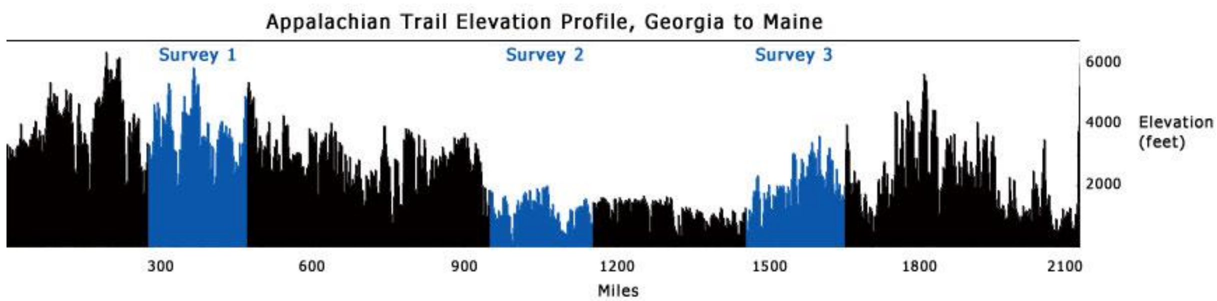

Figure 17. Appalachian Trail elevation profile from GA to ME. This elevation profile is condensed to show the entire Appalachian Trail from Georgia to Maine. The first section before Survey 1 was difficult for hikers when starting out, but it was observed to be easier than the final section after Survey 3.

Hikers who wanted to enjoy the trail more and go at a slower pace did so based on time allotment, financial status and general attitude towards the trail. The enjoyment they experienced on the trail may have contributed to completing the trail with a positive attitude, albeit in a longer time frame. An alternative considered was that many hikers who hiked at a faster pace also enjoyed their hike. Many hikers enjoy setting their own pace as they enjoy the solitude of being alone in the wilderness (Coble et al., 2003). Ultimately there were no measurements in the model for attitude, possible frequent changes in attitude, or the dependencies of attitude on sections of the trail. A variable for hikers with positive moods could have been exercised as a possible predictor in completing the trail; however these types of measurements were not included since they were viewed as subjective in nature solely dependent on the opinion of the participant. Mood and average miles per day seemed unrelated to the larger populous of the study.

Pack load conditions. During factor analysis, three components were identified to explain 70% of all variance in the variables, while two factors explained 62.8% of common variance among the variables. The primary factor that was extracted was the Pack Load Conditions, which accounted for 36.8% of common variance in the model. PW and LP were replaced in the analysis with a composite variable, Pack Load Score (PLS). Both the baseline and last recorded values for PLS loaded together in the PCA along with a medium loading of Injured. This would indicate that the pack weight and load percentages together influenced completing the trail while having an effect on injuries reported.

For the group that completed the trail (n = 24), at the end of the trail *M* PW was 28.75 lb and *M* LP was 18.17%. For the group who did not report completing the trail (n = 60), final recorded weights were much higher with *M* PW recorded as 33.98 lb and *M* LP as 20.75%. The differences between the mean weights carried by hikers was an indication that pack weights played a role in the ability of hikers to cover more miles per day and complete the trail. The ensuing analysis that has found Pack Load Conditions to be the primary factor further supports that pack weights affect the total number of miles hiked.

The pack loads carried by hikers also showed a relationship to the injuries reported when they loaded together in the first component. Pearson product-moment correlation found statistically significant small positive correlations for both PLS variables when tested against Injured. PLS_start verse Injured, $r = .296$, $N = 84$, $p < .05$ and PLS_end verse Injured, $r = .246$, $N = 84$, $p < .05$. These relationships represent a trend that higher pack loads had an association with injuries reported.

A total of 34 hikers indicated at least once in the surveys that they experienced injuries in areas associated with load carriage using backpacks. Those that reported injuries had a combined *M* PW of 35.65 lb as last recorded and *M* LP of 20.77%. Hikers who did not experience injuries ($n = 50$) to their backs, hips or shoulders had a final recorded *M* PW of 30.34 lb and *M* LP of 19.5%. Through additional data analysis it was discovered that approximately 85% of those who reported injuries in the study had first reported those injuries in the first survey. Descriptive means for PW and LP between baseline and the first survey of those injured can be seen in Table 10.

Table 10

Injuries First Reported - Baseline to Survey 1 Means Comparisons

Injuries Reported		PW (lb)	LP	*n*
Injured				
	Baseline	41.34	22.25	29
	Survey 1	36.59	21.14	29
Not Injured				
	Baseline	36.62	21.50	55
	Survey 1	32.45	20.18	55

The mean differences between injured and non-injured reveal that the injured carried an average of 5 lb more than the uninjured. Table 10 only shows the means for the first 29 who reported injuries in the study in contrast to the non-injured in the first survey. Some of those injured hikers who continued on the trail also continued to report injuries across the study. Pack weight and load percentage values for the injured and non-injured across the study are shown in Figures 18 and 19.

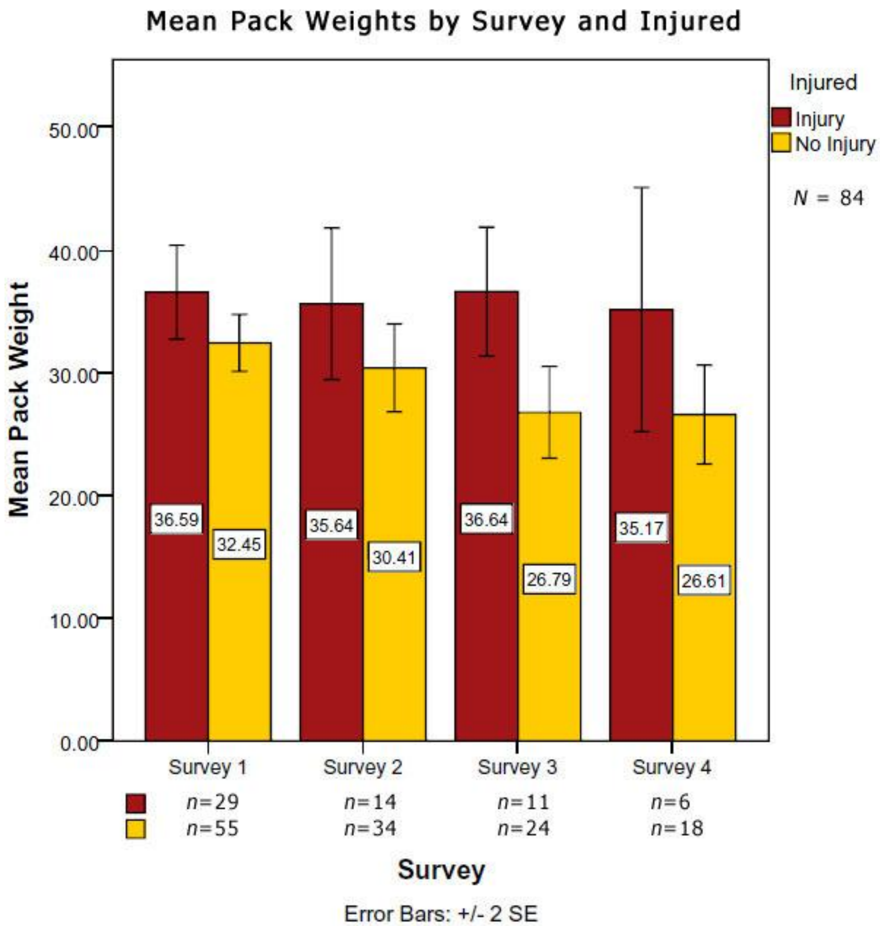

Figure 18. Mean PW bar graph by Survey and Injured. The mean pack weights for hikers who never reported injuries to back, hips and shoulders stayed well below the initial 36.62 lb reported at baseline. The means for inured hikers never dropped below 35 lb. This indicates that hikers who avoided injuries adjusted their pack weights to more comfortable levels while the injured hikers never made pack weight adjustments.

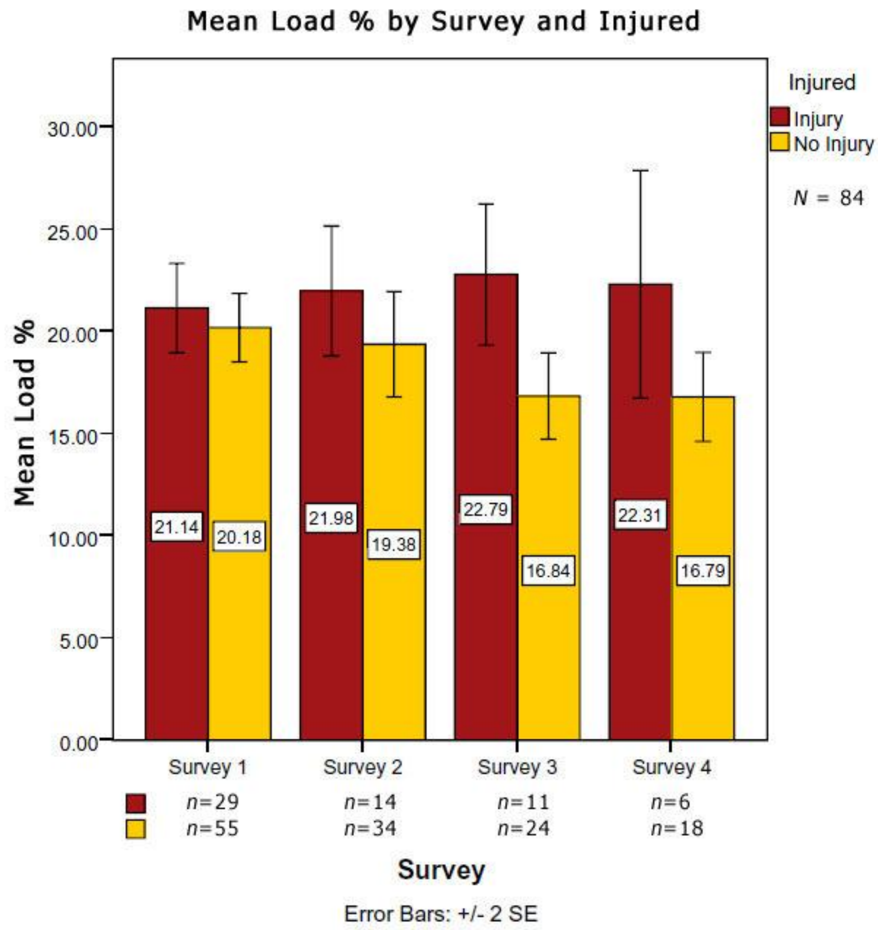

Figure 19. Mean LP bar graph by Survey and Injured. The load percentage of injured hikers appeared to increase as hikers progressed on the trail. Non-injured hikers had a steady decline in LP as they continued on the trail.

In Figure 18, pack weights for the non-injured drop across the study while the injured did not make adjustments. Figure 19 reveals an increase in load percentage across the study for the injured, while the non-injured adjusted pack weights to more comfortable levels. This further illustrates the negative relationship between LP and BMI, as BMI decreased and PW did not change, then LP increased (see Figure 20).

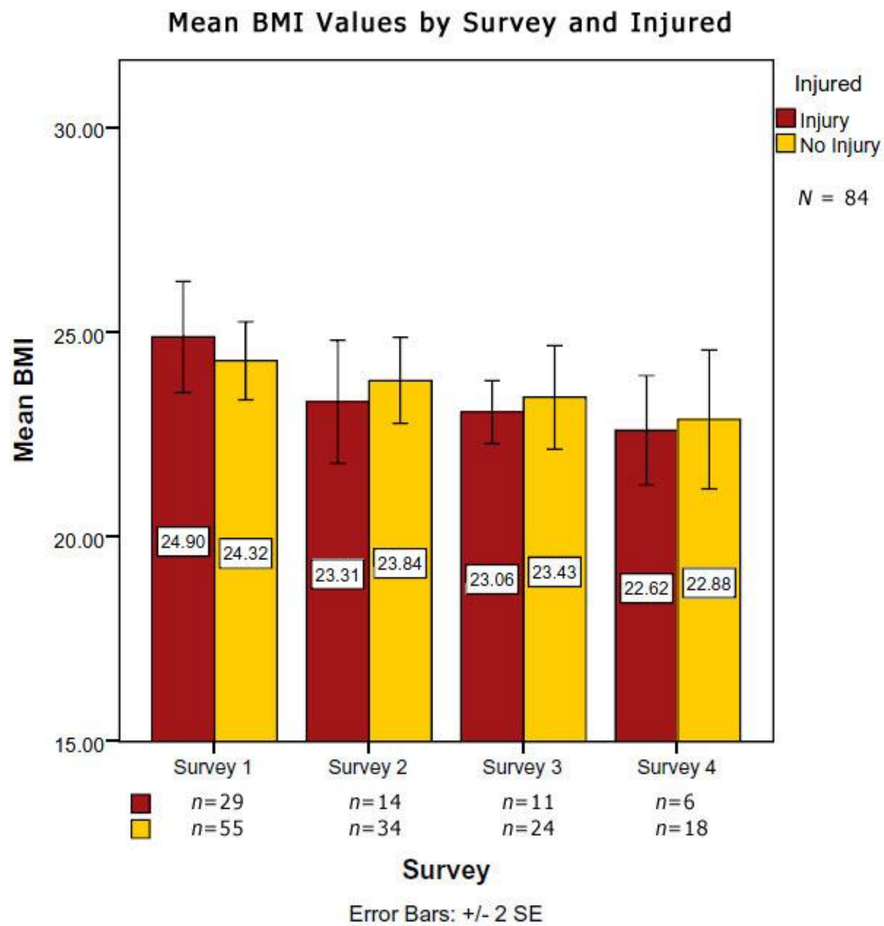

Figure 20. Mean BMI bar graph by Survey and Injured. Mean BMI values dropped at each survey point across the study indicating consistent weight loss. The injured and non-injured had similar BMI values at each survey point with the injured reporting slightly less BMI in surveys 2, 3, and 4. This explains why the LP values are greater for the injured group since their PW was unchanged.

Average miles hiked per day were affected by pack weight and load percentages bringing into question whether AvgMiles was affected by injuries. In Figure 21, AvgMiles are shown to be evenly distributed across the injured categories throughout the study. This is consistent with the findings in logistic regression, which did not list Injured as a significant predictor. PCA also showed that Injured slightly loaded to both the Pack Load Condition and the Gender Weight Differences, not Hiking Rates. Data suggests that pack related injuries did not impact AvgMiles.

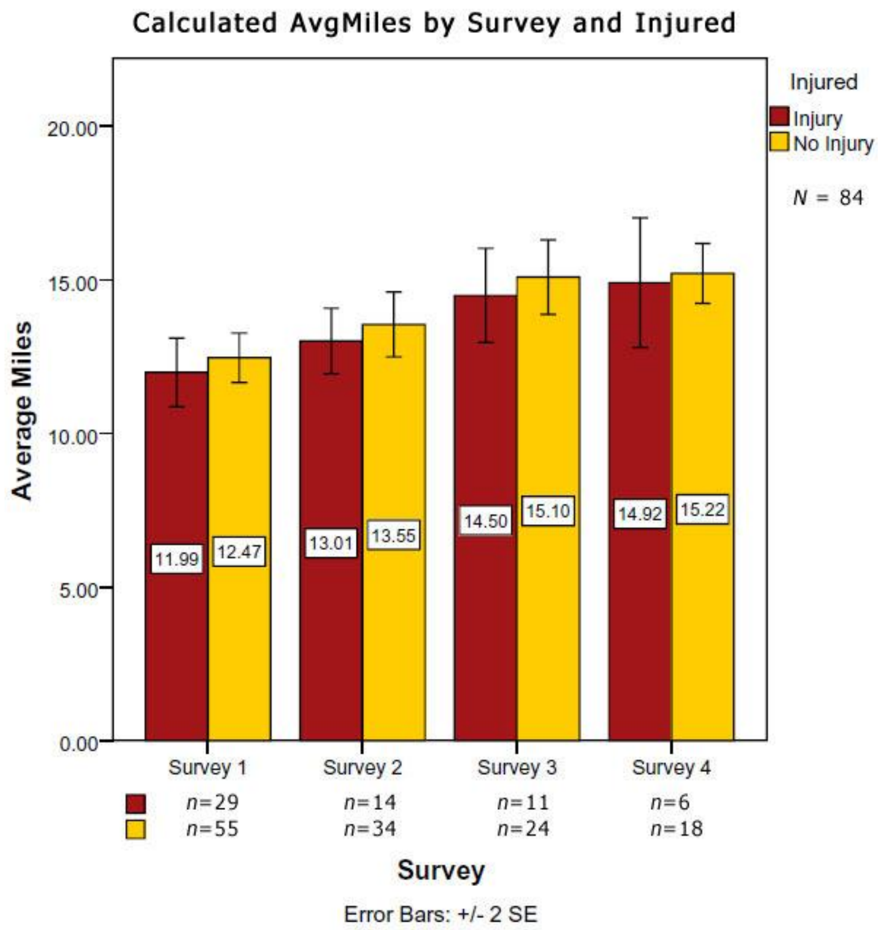

Figure 21. Calculated AvgMiles bar graph by Survey and Injured. The average miles per day increase with each survey. The two groups had approximately the same hiking rate across the study with no more than a 0.6-mile difference at any time.

Hiking rates. Factor analysis found Hiking Rates as a secondary factor where AvgMiles and TotalMiles both had a high loading explaining 26% of total common variance. AvgMiles and TotalMiles both were used to gauge hikers on their ability to travel long distances. AvgMiles used for daily measurements was found to be a significant predictor in logistic regression testing. Those who completed the trail had a mean calculated average of 15.1 miles per day, while those that did not report finishing averaged 12.1 miles per day. TotalMiles was used to determine how far a hiker had travelled before completing the trail. Since the maximum total miles to be hiked in this study was the official entire length of the AT (2184 miles), then there was a relationship between total miles and completing the trail (CompTrail).

In some models used for PCA, the secondary component making up the Hiking Rates factor also had a small load of the modified experience (ExpModified). The variable was removed for having a small communal value in the component. Nevertheless, experience was expected to have some effect on TotalMiles with a statistically significant correlation between the two ($r = .241$, $N = 84$, $p < .05$). A means comparison of average miles per day was conducted between various levels of experience. The ExpModified variable had only two levels of experience, those that had less than 250 miles before hiking the AT and those with over 250 miles. An additional level of experience was added to show the starting pack weight differences of experts with over 1000 miles before hiking the AT (see Table 11).

Table 11

Means Comparisons by Experience

Experience at Start	*n*	PW_start (lb)	LP_start (%)	AvgMiles	CompTrail
Up to 250 Miles	56	39.23	22.39	12.6	13 (23%)
Over 250 Miles	28	36.29	20.48	13.7	11 (39%)
Over 1000 Miles	10	29.40	19.43	14.2	3 (30%)

Note: N = 84. The third group with experience of over 1000 miles prior to starting the trail is a subset of the second group with over 250 miles.

Hikers with more experience tended to have less pack weight and hiked more miles per day. Experience was not found to be a significant predictor in logistic regression and had low communal values during factor analysis, thus not supporting ExpModified as being a variable with common variance. One possibility for this may be a low population count of expert participants in the study for logistic regression and factor analysis. Another possibility could be that the modified variable for experience (ExpModified) was disproportionally aligned by the experience levels. Future studies should include more experts in the analysis with the experience levels represented as individual dichotomous variables.

Gender weight differences. During the PCA a tertiary component had Gender and BMI_end variables load highly with each other. This was not identified as one of the primary factors that could explain common variance because of a low eigenvalue and low communal values. However the interest in Gender Weight Differences caused an analysis of means for men and women who hiked the trail, grouped by CompTrail (see Table 12).

Table 12

Means Comparisons by Gender and Completed the Trail

Gender		*n*	BMI_end	PW_end (lb)	LP_end (%)	AvgMiles
Male	Completed	17	23.00	30.29	18.18	15.4
	DNRF	45	25.11	34.78	19.67	12.4
	Total	**62**	**24.53**	**33.55**	**19.26**	**13.2**
Female	Completed	7	22.41	25.00	18.17	14.4
	DNRF	15	22.50	31.60	23.97	11.5
	Total	**22**	**22.47**	**29.50**	**22.13**	**12.4**

Note: $N = 84$.

While Gender was found to be a significant predictor in logistic regression, the BMI_end variable had a non-significant *p* value of .063, illustrating that gender weight differences may have been caused by chance. Just as seen previously, those who completed the trail had lower pack weights and load percentages while having higher average miles per day than the DNRF group. However finale BMI values for men differed by almost 2 index points with the hikers who completed the trail having the lower BMI values. Female mean BMI values were virtually the same between the two groups. This could suggest that there was an effect on men completing the trail because of higher BMI levels. With the relationship between BMI and PW, it could also suggest that hikers with higher BMI levels carried more pack weight affecting their hike. The latter explanation could be accepted since logistic regression analysis to predict completing the trail requires that all the variables together play a role in the outcome. To better understand the role Gender Weight Differences played in completing the trail, further studies would need to be performed with a larger population including more female participants.

Pack Weight Limits

When hikers are preparing for a long-distance hike they tend to over pack with items they think they will need or use while on their trip. The result is usually a heavy backpack. But what is too much weight? When the women were assessed for long-term load carriage in the Simpson et al. (2011) study, they carried pack weights of up to 40% of total body weight, but only for 5 miles (8 km). Ciriello, Snook, and Hughes (1993) published maximum acceptable carry weights that exceeded 48 lb for 8-hour periods for women and 68 lb for men, however these limits were based on hand carried boxes. Kroemer et al. (2003) state that a medium load evenly distributed across the shoulders can be carried on the back with minimal energy costs, however they use 68 lb (30 kg) as a medium load. These studies do not have a close relation to the load carriage that is attempted by long distance hikers. The weights used in their tests may not be appropriate limits for long distance hiking for months at a time.

When hikers inquire about gear and pack weights with experienced long distance hikers or outdoor retail stores, they are given a variety of information based on different opinions. The information is sometimes based on individual experience of the outdoors expert and at other times, misinformation derived from other fields such as military load carriage regulations. Expert backpackers, who are used to carrying much lighter gear, are usually careful to tell potential thru-hikers to not go ultralight on their first long distance hike. Since carrying less weight can cause a hiker to “go without,” it should be up to the experience of a hiker to decide what they don’t need. On the other hand the experts can tend to vary what they believe to be a good maximum pack weight for hiking a long distance trail such as the AT. This varied information comes from their own learning experiences and other resources. Most tend to believe that 30% of total body weight is the maximum limit (Ray, 2009). This may still be a reasonable limit when compared to other studies that use heavier pack weights with fewer injuries reported (Reynolds et al., 1999). However they may not be the best limits for increasing the possibility of completing the AT.

Improving success and reducing injuries. One of the goals of this study was to identify a better pack weight limit that can help increase success rates for hikers and reduce injuries. The Appalachian Trail Conservancy (2011) states than one in four thru-hikers (25%) complete the AT each year. The current statistics show that only 21% of all hikers completed the trail in the 2012 season (Appalachian Trail Conservancy, 2013). Additional statistics show slightly better completion rates of up to 30% for previous years.

Despite these figures, survey numbers for the total number of hikers are expected to be skewed since it is not required for thru-hikers to register at the ranger station in Amicalola Falls State Park in Dawsonville, Georgia, prior to starting the AT. Many hikers choose not to register since the ranger station is 8 miles from the start of the AT on Springer Mountain. However, the figures of hikers who completed the trail are expected to be more accurate since hikers are required to register with local rangers before attempting to climb Mount Katahdin in Baxter State Park in Maine. These figures may skew the results into looking as if there are higher rates of completion.

Possible pack weight limits for long distance hiking were found in the trends of pack weight and load percentage values among those that completed the trail. These trends showed a particular threshold of pack weight and/or load percentage that was then tested across the study.

Table 13 shows the common weights for those that completed the trail and those that did not report finishing (DNRF).

Table 13

Trends in Pack Weight and Load Percentages

CompTr	Sub-Group	*n*	PW_start	LP_start	PW_end	LP_end
Completed	Total	24	35.92	20.74	**28.75**	**18.17**
	Men	17	37.00	20.68	**30.29**	**18.18**
	Women	7	33.29	20.91	**25.00**	**18.17**
	Experience 250	11	33.91	18.37	**28.64**	**17.69**
	Experience 1000	3	**19.67**	**12.57**	**15.00**	**10.76**
DNRF	Total	60	39.18	22.16	33.98	20.75
	Men	45	40.58	21.07	34.78	19.67
	Women	15	35.00	25.42	31.60	23.97
	Experience 250	17	37.82	21.85	33.53	20.75
	Experience 1000	7	33.57	22.36	30.57	21.40

Note: $N = 84$. Experience had various subgroups. The Experience 250 group was the group in the ExpModified variable with more than 250 miles of experience before starting the AT. The Experience 1000 group was from the original Experience variable with over 1000 miles before starting the AT and the true experts in the study. Bolded values are highlighted trends.

The observed trend in pack weights showed that most hikers that completed the trail had pack weights below 30 lb and/or below 20% of total body weight. With consideration given to these figures as mean values, it is accepted that not all hikers that completed the trail were under these numbers. Minimum pack weight recorded by participants at the end of the hike was 14 lb while the maximum was 50 lb with a range of 36. A total of 7 hikers of the 24 that completed the trail were over both observed thresholds for pack weight and load percentage. It should also be noted that those that completed the trail may have started over these weights, but adjusted their pack weights according to the loss of body mass. This suggests that hikers can potentially start with heavier packs and still complete the trail by lowering pack weights early in their hike.

Using the numbers found in the means comparisons, each hiker in the study was categorized as either over limits (greater than 30 lb and 20% total body weight), within limits (less than or equal to 30 lb and 20% total body weight). A total of 68 hikers were over limits from the start of the trail, 18 of which completed the trail or 26%. Of the remaining 16 hikers within limits, 6 had completed the trail for a 38% completion rate. After hikers adjusted pack weight to compensate for losses in body weight, there were 34 hikers that were within limits, 14 completed the trail for a 41% completion rate. A Pearson's chi-square test for independence showed a statistical significant difference ($\chi^2 = 4.447$, $N = 84$, $p = .035$, and $df = 1$) in that hikers who adjusted pack weights below the suggested limits were more likely to complete the trail. The odds for completing the trail are 1.4 times better for hikers who adjusted pack weights to below 30 lb and 20% of total body weight (TBW). Hikers who finished the trail with a TBW under 150 lb and carried less than 20% of TBW ($n = 10$) had a success rate of 60%. Hikers over 150 lb TBW and carried less than 30 lb ($n = 24$) had a 33.3% success rate. All success rates associated with the observed threshold limits exceed the current success rates and estimations by the ATC. Based on these comparisons of mean values, it can be said that hikers who adjust their pack weights to within limit values, can increase their chances of completing the Appalachian Trail.

When using the same categorization for pack weight comparisons of injured hikers, it was found that there were a high number of hikers that were over those limits. A total of 21 hikers complained of their packs being too heavy or hurt with 20 hikers over the limits or 95%.

Of the 25 hikers who reported that injury was limiting factor to their hike, 21 or 85% were over the limits. A total of 34 hikers complained at least once of injuries to their backs, shoulders and/or hips during their trip, of which 31 were over limits or 91%.

The population of 31 injured hikers came from a total of 68 hikers who were over the limits from the start of the trail causing a 46% injury rate. A total of 16 hikers were under the suggested limits of this study and only 3 of them reported injuries for 19% injury rate. A Pearson chi-square test of independence showed a statistical significant difference (χ^2= 3.872, N = 84, p = .049, and df = 1) in that hikers who started with pack weights below the suggested limits were less likely to report injuries. While there was an observed count of 3 for the under limits/injured hikers, the lowest expected value was 6.48 for the chi-square test. The odds for being over the limits and not reporting an injury were 1.2 (over limits non-injured divided by over limits injured, 37/31). The odds for being under limits and not reporting an injury were 4.3 (under limits non-injured divided by under limits injured, 13/3). This produced an odds ratio of 3.6, meaning that when hikers started the trail under the suggested pack weight limits they were 3.6 times less likely to report an injury than the hikers who were over these limits. The relative risk of injury for hikers over the pack weight limits were 2.4 times of that of the group that was under the limits with an increase in risk by 143%. The conclusion is that hikers who start the trail under the suggested pack weight limits of 20% of total body weight not exceeding 30 lb will report much fewer injuries to the upper/lower back, shoulders and hips.

As a result, this study proposes suggested pack weight limits for long distance hiking should be based on a benchmark total body weight of 150 lb. The limits proposed are the maximum of 20% of body weight if the hiker is less than 150 lb in body weight or a maximum of

30 lb if over 150 lb. These suggested limits could help increase success rates of long distance hikers and reduce the number of injuries sustained by those who use backpacks for long-term load carriage.

Pack weight comparisons. The pack weight limits for long distance hiking that are suggested in this study (the lesser of 30 lb or 20% of total body weight) could potentially create better guidelines in long-term load carriage in other fields that use backpacks. However, the reliability of such pack weight limits may not be high if the domains using these limits do not have similar populations. An example would be that a population of military troops carrying backpacks necessary to complete an extended mission may not necessarily match that of a population of long distance hikers. Military personnel are required to adhere to specific body weight rules and fitness in order to able to perform in their roles, while hikers are not required to be fit to be able to start hiking a trail.

To test the reliability of the suggested pack weight limits in terms of long-term carriage, a comparison of success rates was completed using the suggested pack weight limits and one set of limits that are currently listed in MIL STD 1472-F for load carriage. To do this comparison, the population of hikers was restricted to those who were at normal BMI levels (less than 25 BMI) and under 35 years of age, at the start of the trail. The success rates for each load carriage criterion were then compared.

In comparing the success rates of the different pack weight limits, there were two observations that were noted. First, limits of 30 lb/20% of body weight showed to be more successful with a population similar in BMI and age to military personnel. The completion rate for hikers within the limits of the suggested pack weights was higher than those who were within

Military Standards (MIL STD 1472-F) load carriage limits at both survey points (see Table 14). The opposite was true for injury rates at the start of the trail, which were higher for the hikers within the MIL STD 1472-F limits (see Table 14).

Table 14

Comparisons of Pack Weight Limits

Weights Captured	*N*	Criterion	Within Limits	Completed Trail (%)	Injured (%)
Baseline	31	30 lb/20%	7	3 (43%)	1 (14%)
		41 lb/30%	20	5 (25%)	6 (30%)
Last Recorded	31	30 lb/20%	14	6 (43%)	4 (29%)
		41 lb/30%	28	9 (32%)	10 (36%)

NOTE: The criterion of 30 lb/20% is the suggested pack weight limits of this study while 41 lb/30% are one of the pack weight limits of the Military Standard (MIL STD 1472-F).

The second observation, injury rates were lower when hikers started within pack weight limits. The increase in injury rates between baseline and last recorded values is due to more participants falling within weight limits later in the study after adjusting pack loads. Injuries occurring during the hike may have been the catalyst for participants making those changes.

Comparisons of the same group of physically fit hikers with different load carriage limits, showed that higher limits would have provided less success and potentially more injuries. In addition, extending these pack limit comparisons across the entire population regardless of age and body mass, showed similar results. Hikers that started within MIL STD limits had a completion rate of 27% verse 38% for the group within the suggested limits. Across the surveys, the comparisons were 31% verse 41% in favor of the lower limits. Using 30% of total body weight in backpacks typically produces the same results that are currently seen in the success rates of all hikers on the AT.

The success rates of hikers using these limits in this comparison may provide useful in the backpacking industry, although the measurements for success vary in other domains. Just as military load carriage limits are shown to not be as successful in the backpacking industry, suggested limits of this study may not provide mission success in military operations. However, the injuries reported in the comparisons of the load carriage criterion suggest that the heavier weight limits will provide higher incidents of injuries, a measure that is similar across domains. The Knapik et al. (2004) study on load carriage with packs also suggests using lighter loads as larger volumes cause greater expenditure of energy, decreased ability to perform tasks, and increased incidents of injuries. These effects are all common to the back packing industry. Creating a standardized index of pack weight descriptions would be helpful in future studies of load carriage and the effects of the volume carried.

Discussion

This study showed through analysis that packs with larger loads can affect hikers negatively in the number of miles hiked both daily and in total. Hikers that completed the trail had pack weights and load percentages that were lower across the study than those who did not report finishing the trail. Additionally those hikers who reported pack related injuries were consistently higher in pack weight than those who did not report injuries. Trends show that hikers, who adjusted their pack weights according to body mass reductions, had lower injury rates and higher success rates. The conclusion is that hikers should carry less than 20% of their total body weight and no more than 30 lb. Hikers who are over one of these limits may still have great success and fewer injuries, however they should avoid being over both limits.

Evaluating hikers strictly by the pack's load percentage of total body weight did not produce any significant results in this study. Most hikers landed in either two of the four total categories created. Neither of those most frequented categories showed any greater advantage over the other for completing the trail. The study redesign to logistic regression analysis did support that both pack weight and load percentage were needed for predicting the outcome. In addition, pack load limits can better be supported using both criteria.

Pack Load Score

During the course of analysis, pack weight and load percentage variables were found to be too highly correlated for use in factor analysis and a composite variable was created. Pack Load Score (PLS) is calculated by scoring both the pack weight and the pack's load percentage of total body weight. These scores are added together to create an index value that can be used when describing the total load of a pack as maximum values. The scale of the variable starts at zero and can be infinitely positive depending on the amount of weights being measured. In this study the scale was only calculated from 0 to 7.

The advantage of creating this variable is that it can be used to create standardization in the backpacking industry for pack weight limits. When used on the suggested pack weight limits of this study, 30 lb / 20% of TBW, the scale would show hikers to be within weight limits with a score value of 3 or less. Pack loads of 4 to 7 would be considered over the limits. The calculation instructions for Pack Load Score can be shared with hikers through online media, retail outlets, and literature from pack manufacturers. When the Pack Load Score is used to describe pack weight limits to potential hikers of the Appalachian Trail, they can self assess their pack weights when it is suggested to maintain a Pack Load Score of 3 or less.

Other potential uses for the Pack Load Score could come in similar studies of long distance hiking in shorter time frames or in different environments. A possible place where suggested pack weight limits could differ would be on the Continental Divide Trail (CDT) where hikers go many more days in between food resupplies. This would increase the potential weight of a backpack under those circumstances. Using PLS in an investigative study of better success rates for the CDT would provide data relevant for pack manufacturers and potential hikers of that specific community.

Pack Load Score can be used in any application where load carriage may affect an outcome. Backpack manufacturers could use the PLS for describing the potential maximum weight for a particular pack and its suggested use. Studies on children's backpacks for school could be categorized with PLS values. Studies on lower body amputees could use an index of pack weight to help determine the backpack load carriage ability for users with prosthetics. Other short-term load carriage duties such as packing emergency medical equipment to remote locations could benefit from using pack load scoring. Regardless of the duties, PLS values can be standardized to fit the domain.

Study Strengths and Weaknesses

The strengths of this study come from the way the study was conducted. In order to assess injuries, pack weight, and hiker performance, measures needed to be taken over the entire length of the hike. Getting participants involved early in the study that only took a few minutes per survey, helped to obtain more data across the survey. Capturing the injuries reported by the hikers who did not report finishing the trail and the pack weights they carried, filled in gaps that were previously created in other studies on injuries and pack weight (Anderson et al., 2009; Gardner & Hill, 2002). The longitudinal study of the participants and their history of pack weights helped in illustrating the effects of heavier loads carried by hikers. Through the use of accessible internet surveys and email reminders, pack weight values are more accurate as they were captured in real-time, eliminating recall bias. Additional information was captured from hikers to hide the study's primary focus on pack weight, causing more data to be collected for other possible studies. Surveys used in this study can be reused to capture more data from future hikers. One of the most significant contributions to this study was the observations made by a researcher who participated in hiking the entire trail in 2012.

The most important researcher observations in this study came from the knowledge of relevant factors, such as the difficulty of terrain, weather conditions, needs on the trail for pack loads, and other reasons outside of pack weight that can give explanations for data patterns. This knowledge also helped data analysis as the focus was directed towards only the relevant information. An added benefit of having a thru-hiker conducting the study was that other hikers were more willing to participate when they learned the researcher was a part of their small community.

There were a few limitations and difficulties experienced while conducting the study. The first difficulty was setting up the survey reminders which required a preparation trip along the trail at the survey points before the hiking season began. Recruiting participants was also a challenge with posted notices as only 20% of the participants registered from the postings. The major limitation was that it was an internet-based study of a population of people in remote areas with no Internet access. The study relied on Internet access provided in towns at hostels, hotels and libraries, which were at times limited by available computers. This may have led to some hikers not following directions and filling out two surveys at once or skipping a survey, causing the removal of data. Limited Internet may have also caused the attrition of some hikers from the study as they did not report finishing the trail and did not give reason why in an exit survey. The desired population was not reached in the study causing a slightly low Kaiser-Meyer-Olkin value during factor analysis; however the population was large enough for logistic regression analysis. By using the current hiking community, there was little chance to create even categories based on load percentage, causing fewer participants in the lowest and highest categories. Despite limitations, trends in pack weights are apparent and can give insight into increased success and fewer injuries.

Summary

This study found trends in pack weight that can lead to potentially higher success rates and lower incidents of injuries. The suggested pack weight limits of 20% of total body weight to a maximum of 30 lb has the potential to increase the current estimated success rates for hikers of the Appalachian Trail beyond the current estimated 25%. It was found that hikers who carried pack weights within those limits in this study had a success rate of over 40%. It was also found that the number of reported injuries to the upper / lower back, shoulders, and hips were minimized for hikers within those pack weight limits with an injury rate of only 19%. These improved rates also show better performance for hikers as they completed more miles per day. Better success and fewer injuries from the lower pack weights expose the current generalized suggested definition of 30% of total body weight as an ancient limit for the backpacking domain.

The misconception in the backpacking industry is that pack limits similar to other industries or domains is good enough for long distance hikers. Advising hikers to carry up to the same amount of pack weight that a combat ready soldier carries does not improve the hiker's ability to complete a long distance trail or avoid injuries. Hikers that were similar to military personnel from the start of the trail recorded higher injury rates and lower success rates when they were within the military load carriage standards for pack weight, as opposed to the suggested pack weight limits of this study. Using the study population of hikers, this finding gives additional evidence to the need of lowering pack weights in the hiking community.

The creation of the Pack Load Score was initially to accommodate multicollinearity issues during factor analysis. However the resulting value of pack weight scores added to load percentage scores shows that maximum values can be represented in studies and the industry as a single number. Pack Load Score is easily calculated and can be taught to potential hikers as they prepare for a long distance hike. The indexing scheme can also be used to address maximum suggested limits on other trails and for equipment development. This could potentially bring standardization to the backpacking industry for pack weight descriptions.

Consistently higher success rates from the suggested pack weight limits illustrate the need for potential long distance hikers to become more informed in pack weight limits. Retailers, backpack manufacturers, and experts in the industry have the ability to inform hikers of the potential dangers and setbacks that can be caused by carrying too much weight. By using the information in this study as a teaching tool, they could eventually see more hikers completing long-distance hikes and suffering fewer injuries.

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Appendix A

Informed Consent Form

Next page.

Effects of Pack Weight on Endurance of Long Distance Hikers

Conducted by Anthony Thomas

Advisor: Dr. Jason Kring

Embry-Riddle Aeronautical University

Daytona Beach, FL 32114

The study you are about to participate in will be analyzing the pack weight of hikers. The purpose of the study is to see how pack weight affects the endurance of a thru-hiker. Information that will be collected through online surveys will include pack weight, body weight, gender, injuries/illnesses sustained, backpack type, shoe type, miles hiked, and zero days. This experiment will consist of three section surveys, a pre-hike survey and a short exit survey. All surveys will be conducted online at the Hiker Survey website (http://www.HikerSurvey.com). Each survey should last five to fifteen minutes depending on your answers

To be eligible to participate in the survey you must be at least 18 years of age and intend to thru-hike the Appalachian Trail. You will be required to register on the Hiker Survey website using an email address and password. Hikers participating in the study will be eligible for various outfitter gift cards and/or other prizes (up to $500 in value each) that will be given away though random drawings at the end of the study. The drawings will be held privately by the study administrators on December 3, 2012 and winners will be notified via phone or certified mail. If you wish to be placed into the drawings for one of several outfitter gift cards and/or prizes, you will need to provide further contact information at the end of the study to include full name, address and phone number. This information will not be sold or used for any other purpose than for contacting winners of the drawing and will only be accessible by the study administrator. Emails will be sent to remind you of the survey locations and your participation until the exit survey has been completed or you opt out of the email reminders.

You will be asked to take the online survey once during each of three sections of the Appalachian Trail (Southern States, Mid-Atlantic States and New England States). The order in which the surveys are filled out is not significant so to accommodate all hikers regardless of hiking itinerary, north-bound, south-bound, or flip-flop. Survey announcements will be posted in hostels, hotels, outfitters and public libraries where free internet access can be provided to the online surveys. The listings of hostels, hotels, outfitters and libraries will be published on the Hiker Survey website, although it is not required to fill out the survey at those locations. Access to the Hiker Survey website is encouraged from any location within the survey section (see the website for specific information on survey sections). Pre-hike surveys will be conducted at the same time as your first survey and may add five minutes to survey time. Once your hike has ended, you will need to complete an exit survey to qualify for outfitter gift cards and/or prizes. Only complete the exit survey when you are sure you have finished hiking. Successful completion of your thru-hike is NOT required to complete the exit survey or to qualify for the outfitter gift cards and/or prizes. Participants who do not complete the four total surveys will still be eligible for outfitter gift cards and/or prizes of lesser values (up to $250) as long as they complete the exit survey and have provided their contact information. An estimated $2500 in total outfitter gift cards and/or prizes will be given away in the random drawings.

The participants that are active in the survey are asked not to force themselves to keep hiking just because they are participating in this study. Hikers should follow the general rule of "Hike your own hike". The administrator of the study will not be held responsible for any injuries or sickness that may fall on participants. The risk of hiking the Appalachian Trail is solely that of the participant. Participants may withdraw from the study process at anytime by simply not completing future surveys.

For questions contact the Survey Administrator at: tony.thomas@gmail.com

Statement of Consent

I acknowledge that I am at least 18 years of age, my participation in this survey is voluntary and that I may withdraw at anytime. I have been informed of the general scientific purposes of the experiment and will be included in a drawing for outfitter gift cards and/or prizes if I choose. If I withdraw from the experiment before completion then I forfeit my rights to be included in the drawing for outfitter gift cards and/or prizes.

Electronic Signature

By typing your name and clicking the Agree button you are agreeing to the terms of the survey ____ Date: *Autofilled*

Appendix B

Survey Questions

This list represents the data that the online survey will capture for Appalachian Trail hikers to access their pack weight, factors that affect carrying the weight and factors for quitting a long distance hike.

Registration

The registration process will require basic information:

- Name or Trail Name
- Email Address
- Gender
- Age

Questions during registration will give a baseline of information on the hiker:

- Start date
- Starting body weight, height
- Starting backpack base weight (no food or water)
- Starting backpack pack weight (with food and water)
- Assessment of athletic ability with a scale for experience level
- Assessment of backpacking experience with a scale for experience level
- Listing of preconditions of injuries like musculoskeletal, soft tissue damage, joint pain, foot/leg injuries, and preexisting nerve damage.
- Listing of existing illnesses like Lyme disease, heart disease or diabetes.

Basic equipment usage that affects carrying the weight

- Back pack type and model
- Type of shoes worn: rigid sole, flexible sole, sandals
- Trekking Pole use: yes or no

Each hiker will be given a chance to tell why they decided to hike the Appalachian Trail (to keep hikers interested in the survey, they long to tell their story)

Each Section Survey

Check for changes in basic equipment

- Back pack type and model
- Type of shoes worn: rigid sole, flexible sole, sandals

- Trekking Pole use: yes or no

Questions during each section survey

- Total Days hiking since the start of the hike
- Total Days off
- Total miles hiked
- Current body weight
- Current backpack base weight
- Average backpack pack weight over last 2 weeks
- Injuries experienced? If so did they see a physician?
- Illnesses experienced? If so did they see a physician?
- Are they tired of hiking the trail? if so why? Possible multiple answers (bored, lonely, injuries, illnesses, weather, animal encounters, dealing with other hikers, carrying weight, other)
- Do they feel hiking the AT is a good experience?

Exit Survey

Check for changes in basic equipment

- Back pack type and model
- Type of shoes worn: rigid sole, flexible sole, sandals
- Trekking Pole use: yes or no

Questions during the exit survey

- Total Days hiking since the start of the hike
- Total Days off
- Total miles hiked
- Current body weight
- Current backpack base weight
- Average backpack pack weight over last 2 weeks or since the last survey
- Injuries experienced
- Illnesses experienced
- Why are they quitting the trail? Possible multiple answers (Completed the Thru-hike, family emergency, injuries, illnesses, fatigue, pack too heavy or hurt, weather, animal encounters, dealing with other hikers, bored, lonely, or other)
- What is the single biggest reason for quitting the trail if not complete or an emergency? One answer allowed (injuries, illnesses, fatigue, pack too heavy or hurt, weather, animal encounters, dealing with other hikers, bored, lonely, or other)

Appendix C

Survey Announcement

Next page.

ATTENTION A.T. THRU-HIKERS

Take part in a study and you could find yourself winning one of several gift cards or prizes!

The study: The purpose of the study is to see how pack weight affects the endurance of a thru-hiker. This study will consist of three separate surveys and a short exit survey. All surveys will be conducted online at the Hiker Survey website (http://www.HikerSurvey.com). No personal information is collected unless you wish to be included in random drawings for prizes worth up to $500 each. All you need is an email address and trail name to register!

Eligibility: To be eligible to participate in the survey you must intend to thru-hike the Appalachian Trail. Hikers participating in the study will be eligible for various outfitter gift cards and/or other prizes (up to $500 in value each) that will be given away though random drawings at the end of the study. The drawings will be held on December 3, 2012 and winners will be notified via phone and/or certified mail. Participation is completely voluntary.

Study Coordinator: Thru-hiker Tony Thomas – "I'm conducting this study for my thesis on pack weight. What better way to administer the study than thru-hiking the trail myself!"

For more information please visit:

HikerSurvey.com

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