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To the Graduate Council:

I am submitting herewith a thesis written by Rachel Louise Duckham entitled "The Effects of Hiking Poles on Performance and Physiological Variables During Mountain Climbing." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

David R. Bassett, Jr., Major Professor

We have read this thesis and recommend its acceptance:

Eugene Fitzhugh, Edward T. Howley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Edward T. Howley

Accepted for the Council:

Vice Chancellor and
Dean of Graduate Studies

Thesis
2006
.D83

THE EFFECTS OF HIKING POLES ON PERFORMANCE AND PHYSIOLOGICAL VARIABLES DURING MOUNTAIN CLIMBING.

A Thesis Presented

for the Master of Science Degree

The University of Tennessee, Knoxville

Rachel Louise Duckham

August 2006

DEDICATED

In Loving Memory of my Grandfather, I wish you could have been here!

This is dedicated to my family, who has always supported me. Their words of encouragement in all I have done has helped to make this part of the journey of life an easier one to achieve. I would also I like to dedicate this to a close friend of mine, without him I feel I would have given up on pursuing my college dream a number of times. Carlos, thank you for all the support you have given me over the past few years. My heart goes out to each and every one of you.

ACKNOWLEDGEMENTS

The author would like to express her thanks and appreciation to several people who helped with this project.

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Dr. Gene Fitzhuge and Dr. Ed Howley for serving as members of my thesis committee and always having their doors open and willing to answer any questions I may have. Thank you for the guidance; I have learned so much from you both, however I know I have so much more to learn I just wish I had more time to learn from you all not only in terms of research but also academically.

Dr. D Thompson; even though not on my committee a special thanks goes out to this person for everything she has done for me while I have been at the University of Tennessee. When I first arrived I was scared of Dr. Thompson but over the past two years my fear has turned into the utmost respect. I just wish I had more time to work in person with her.

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A very special thanks goes out to all of the subjects who participated in this study. Without you all this would not have been possible.

ABSTRACT

The primary purpose of this study was to compare performance when hiking with and without poles during a maximal effort mountain ascent. In addition, the study determined if there were differences in physiological responses, such as heart rate, estimated energy expenditure, and blood lactate accumulation. 15 physically active men and women (mean age 29±6) hiked with and without walking poles up a 4-km trail (426-meter elevation gain). Performance was determined by the time taken to reach the top of the mountain. In addition, differences in physiological variables including heart rate (HR), estimated energy expenditure (EE), and blood lactate accumulation were measured. When hiking with or without poles, there were no significant differences found for any of the variables tested. Time-to-completion (53.24 ± 5.31 vs. 52.74 ± 4.47 min) and blood lactate (LA) accumulation (6.23 ± 2.5 vs. 7.23 ± 3.88 mmol/l) were similar with and without poles, respectively. Similarly, no differences were seen for HRmax, average HR, and estimated EE, all variables displayed by the Polar heart watch. In conclusion, performance and physiological responses do not differ when hiking with and without poles on a 4-km mountain ascent. However the subjects reported informally that the poles reduced the lower back and lower extremity pain the day following the hike. Even though no significant differences were found in the ratings of perceived exertion between the two conditions (poles vs. no poles, respectively) 14 out of 15 subjects indicated in a follow up interview that they felt the poles made the effort easier.

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CHAPTER I

INTRODUCTION

Physical inactivity is a major health problem within the United States of America [1]. A lack of time and a shortage of affordable fitness facilities are frequently cited as barriers to physical activity [2]. In recent years walking has been suggested as a feasible exercise mode for individuals who need to increase their physical activity. It is a low impact activity, inexpensive and it can be carried out almost anywhere at anytime. Regular walking can lead to a number of health benefits such as increased aerobic capacity, decreased blood pressure, and enhanced glucose control. Walking can also relieve stress and improve a person's state of well being [3-10].

Walking is a feasible starting exercise for previously inactive individuals, but as fitness levels improve walking speeds must increase in order to see additional improvements. This means that individuals may need to engage in race walking or jogging in order to achieve a cardiovascular training effect. However race walking is a skill that is not easily acquired, and jogging can lead to problems such as lower extremity injuries [11-13].

An alternative exercise mode is walking with poles. This provides more of a total body workout but avoids the high impact forces of jogging. Walking with poles is not new; in fact it has been around for decades. Hikers and mountaineers have long used walking poles to aid in going up and down hill, under the presumption that they increase safety over the uneven terrain, ease the strain placed on the spine and lower extremities, enhance balance, and reduce the impact forces on the body [14-21].

Pole walking originated in Finland and was initially practiced in the 1930's by the Finnish cross country skiers who used pole walking as a form of summer endurance

training in order to keep fitness levels high during their off season. Due to the popularity of pole walking, the sport of Nordic walking was launched in 1997. Nordic walking is similar to cross-country skiing, but on foot. In the year 2000, 500,000 people in Finland participated in Nordic walking [22-24].

When walking with poles it is important to have the correct technique (Figure 1). You should walk naturally but lengthen your steps by around 5% compared to your normal stride. The shoulders should be relaxed with the hands and poles close to the body. A forward stride is taken with one foot and the opposite arm; the pole is planted and then the arm swings backwards as the other arm and leg move forward. The poles should be adjusted to the correct height, making sure that when the poles are planted the elbow is at a 90° angle [22, 25]. Today, almost one-quarter of the Finnish population uses pole walking as a form of fitness. The popularity of pole walking has spread across Europe and it is growing in popularity in the United States [22].

Biomechanists have conducted research on the use of hiking poles. The use of hiking poles has been shown to reduce loading of the lower extremities and therefore, may reduce injuries over a long period of time [14-21, 26].

Walking poles have not only been researched for the beneficial effects they have for reducing lower extremity loading while hiking, but also for the belief that they can increase the physiological responses while fitness walking in a safer way than walking with handheld weights, since they do not require the participate to swing the arms in a vigorously action [27]. Researchers [17, 19, 27-31] have indicated that pole use can increase oxygen consumption by 12-23%, and increase heart rate by up to 18 beats per minute. However, the literature shows conflicting results of the benefits of walking with poles. Some [19, 29, 31] believe the individual is able to

Figure 1: Shows the correct pole technique when hiking with two poles.

increase the intensity of the workout while reducing/increasing the rating of perceived exertion (RPE), others state that physiological responses such as oxygen uptake, and heart rate remain the same even through RPE changes. [17, 18, 30]

A limitation of past research on pole walking is that most of these studies have used treadmills, which do not account for the pole ground interaction and uneven terrain that occurs in the natural environment [19, 31]. Only two studies have examined the use of hiking poles in a field setting [17, 31]. The first [31] used Nordic poles on a level surface with no load, whereas the second study [17] used hiking poles on a graded surface while carrying a backpack.

Purpose

No studies to date have examined the effects of hiking poles on maximal exercise performance in a field setting. Thus, the purpose of this study was to determine the performance differences when walking with and without poles during a 4-km maximal effort mountain climb. In addition, the study determined if there were

differences in physiological responses such as heart rate, energy expenditure, and blood lactate accumulation.

Hypotheses

Based on previous research we hypothesize that:

1. There will be a performance difference in the amount of time taken when hiking with and without poles during a maximal effort mountain ascent.

2. There will be differences in physiological responses, such as heart rate, energy expenditure and blood lactate accumulation when hiking with and without walking poles during a maximal effort mountain ascent.

CHAPTER 2

REVIEW OF LITERATURE

The primary aim of this study is to add to the growing research of pole walking and help to elucidate the potential benefits of using walking poles. In order to do this, it is important to identify a number of topics from the prevalence of walking in the United States, to arm and leg exercise, to a review of a new form of exercise that could enhance leisure time physical activity (LTPA).

Prevalence of Walking as a Physical Activity

The nation's priority for the next four years is to increase physical activity, as it has been associated with a reduction in risk for heart disease, diabetes, colon cancer, osteoporosis, high blood pressure and the prevention of obesity [1]. The objectives of *Healthy People 2010* are to provide direction for health promotion activities, and increase the percentage of people who participate in regular, preferably daily activity from 20% to 30% [1]. The guidelines suggest that sedentary people should first participate in low intensity physical activity, and slowly increase the duration and frequency of the activity. The aim is to have the nation participate in moderate physical activity for 30-60 minutes three to five days per week preferably every day [32, 33]. According to Siegal et al [34], walking is the most popular leisure time physical activity (LTPA) in the United States, but many individuals participating in walking as LTPA are still not reaching the ACSM recommendations for physical activity. The popularity of walking is not surprising considering it is inexpensive, accessible, low impact and is considered an efficacious exercise for weight loss and maintenance [35]. According to the Centers for Disease Control and Prevention (CDC), walking is the most popular leisure time activity and from 1987 through 2000

the prevalence of walking for LTPA increased modestly. Nevertheless, the overall trends for LTPA have remained the same from 1990 through 1998 [35, 36], and the prevalence of overweight adults between the age of 20 and 74 years has increased from 25% to 33% in the past 12 years [37, 38]. The main reason for LTPA remaining constant over the years is related to barriers to physical activity. A recent study [2] indicated that time was the most frequently cited barrier followed by not having an exercise partner, health problems, financial cost and lack of facilities. Interestingly, the current population has more leisure time than ever before, according to Robinson and Godbey [39].

Exercise Prescription for Walking

Important elements for exercise prescription for any activity are duration, frequency and intensity. According to the American College of Sports Medicine [32, 33] in order to improve aerobic power an individual should perform aerobic exercise for 30 to 60 minutes, 3 to 5 days per week at an intensity of 40/50 - 85% of functional capacity. This corresponds to 60 to 80% of heart rate reserve. For years many people viewed walking as an activity suitable for cardiac rehabilitation, sedentary, elderly or overweight individuals, due to its low to moderate intensity level. Recent studies however, have shown energy cost data indicating that the intensity of walking can range from light to heavy depending on the fitness level of the individual [4, 5, 8-10, 13, 40-45].

Energy Cost of Walking

As the most popular LTPA, walking for pleasure is a well accepted activity that brings numerous health benefits, such as improved aerobic power, reduced body mass and percent body fat, decreased depression/anxiety, decreased total blood

cholesterol and increased HDL cholesterol [3-9]. Walking is a rhythmic, dynamic form of aerobic activity, which predominately uses the lower extremities. The average 75 kg male uses between 12 to 15 kg of skeletal muscle while walking, [40] which is approximately half the total body's muscle mass. Walking is a low impact activity, which minimizes joint pain and injury. When compared to running, the ground reaction forces are 3.6 times less in walking, resulting in less stress to the lower extremities [10, 46].

As with other physical activities, walking leads to a number of physiological responses such as improvements to the cardiovascular and respiratory systems. The magnitude of the physiological responses of walking will vary depending on the speed of the activity. Walking at a normal walking pace of 5-km will increase the body's metabolic rate by three-folds from the resting levels, i.e. approximately 13 to 17 kJ/min [43]. It has been stated that at any given walking speed, the energy cost is proportional to a person's body weight. Hence a woman usually expends less energy than a man [47]. When walking on a slope the energy cost of walking will be increased. Walking on a 5% grade at the same pace as walking on a level surface will increase the energy cost by at least 50% [48, 49]. The relationship between walking speed and energy cost is linear at speeds approximately 4 to 6 km/h, and is curvilinear between 6 to 10 km/h [10, 33, 50, 51].

In terms of intensity, a healthy individual should exercise at approximately 60% or more of VO_{2max}, which is equivalent to 70% heart rate max (HR_{max}) [40, 52]. Therefore, a brisk walk at 6 km/h can bring the heart rate into the optimal training zone and improve cardiovascular fitness between 9 to 28% [5, 6, 40, 53, 54]. According to Duncan et al. [53] improvements in VO_{2max} will be proportional to the

speed adopted; for example those who participated in speeds of 6.4 km/h saw a 9% increase in VO_{2max} whereas those who walked at speeds of 8km/h saw a 16% increase in VO_{2max}. It is recommended that in order to see health benefits women should walk between 5.6 and 6.4 km/h and men should walk 6.4 and 7.4 km/h. These speeds will correspond to the 70% of heart rate max [8, 40].

There comes a point where the speed at which a person can walk to achieve improvement is too great and race walking or jogging must be performed in order to achieve the desired training level or target heart rate. Margaria et al. [50] found that the energy cost of jogging at any speed for 1 km is approximately twice that of walking 1 km at 4 km/hr. However, there are a number of individuals who cannot progress to the higher intensity workout due to age, being overweight, or having cardiovascular disease. Jogging can also lead to a number of lower extremity injuries due to the higher impact placed on the joints [11-13, 54]. In a recent study it was found that after a six-month endurance-training program conducted at high intensities of jogging and low intensities of walking, the walkers trained more frequently than joggers. The joggers experienced one-third more injuries than the walkers. It was also found that the endurance capacity of each group increased after the six-month intervention at a similar rate. This indicates that the total accumulated quantity of energy expenditure rather than the intensity is important for cardiovascular improvement [54].

Exercise with Arms, Legs and Arm plus Legs

Walking is a predominately lower extremity exercise, but vigorous arm action, walking with handheld weights or poles can result in a measurable increase in energy cost, even at reduced speeds [10, 47, 55-57]. When handheld weights are carried at

the side of the body without movement VO_2 changes are not seen, however when individuals pump the arms a significant increase in VO_2, a 12 beat/min increase in heart rate, and a 1 MET increase in energy cost are observed [55, 56]. In contrast, when walking with poles the planting of the pole increases the muscle mass recruitment of the upper body, a 23% increase in oxygen consumption, as well as an increase in heart rate by 18 beats per minute [29-31]. These added movements could help to increase the intensity of the workout.

In order to explain the change in physiological responses of walking with added arm action it is important to examine exercise responses of leg, arm and, leg-plus-arm work. Christensen [58] stated that the volume of oxygen consumed during physical exercise would depend on two variables: (a) the load placed on the muscles and (b) the mass of the muscles at work during the exercise. It is believed that leg work can convey a higher level of metabolism than work produced by the arms alone. A combination of both arms and legs can result in a higher maximal uptake than legs alone [44, 45, 58, 59]. Researchers [45, 58-60] reported that an activity such as skiing which uses a combination of arm-plus-leg work achieved a higher maximal oxygen uptake compared to running and cycling. When adding arm work to a running motion it has been found that VO_2 increases by 0.2 liters/min compared to running alone [59]. The above studies show that the amount of muscle mass recruited to produce work is an important factor for VO_{2max}; however each of these studies only used one subject.

Astrand et al, [45] studied the maximal oxygen uptake and heart rate in various types of muscular activity. Seven subjects took part in the study that involved a combination of maximal work of the arms, legs, arms-plus-legs in pedaling bicycle

ergometers, running on a treadmill, skiing, and swimming. The results of the study did not confirm observations from other researchers [44, 59] who stated that maximal work with arms-plus-legs such as in simultaneous arm cranking and running or in skiing gives a higher oxygen uptake then exercising the legs only. Thus Astrand et al [45] state that oxygen uptake seems independent of the mass of muscle employed in the exercise as long as it exceeds a certain mass; instead it is believed that the capacity of the heart is the limiting factor for VO_2. Interestingly, the duration at which a fixed workload could be tolerated by an exercise involving arms-plus-legs is longer than that of legs alone. Therefore, a higher heart rate and cardiac output can be achieved for longer when the larger muscle mass is recruited [45]. When comparing blood lactate accumulation, similar amounts were found with all exercise combinations.

For practical purposes, leg VO_{2max} when running on a treadmill, cycling, or cross-country skiing is similar. However, when cycling on a cycle in a supine position at maximal effort it has been found that the oxygen uptake is only about 85% of that measured in the upright position. When simultaneous arm cranking is added to the supine cycling the oxygen uptake, heart rate and cardiac output values increase to values seen when cycling in the upright position [61]. One explanation for the lower oxygen uptake values of maximal cycling in the supine position is that the body weight cannot be utilized during the vital stages of pedaling because of the unfavorable body position of lying down.

In arm exercise, it has been found that the maximal oxygen uptake is only 70% of that measured in leg exercise [52, 62-64]. During arm exercise the intra-arterial blood pressure and heart rate is higher at any given VO_2 compared to leg exercise. Therefore, heavy arm exercise could be hazardous to untrained older adults

[52, 61, 65-67]. At one point it was believed that the highest oxygen uptake that could be achieved would occur from a combination of arm and leg exercise, depending on the load at the arms. Bergh et al, [62] found that when the arm work was 20-30% of the total work rate in combined arm and leg exercise, the VO_2 was the same as that of maximal running. Interestingly, even though the VO_{2max} was the same for the two types of exercise, the duration for which the exercise could be performed at the same VO_2 was longer when using the arm plus leg combination [45, 61].

Gleser et al [68] studied ten subjects having them complete leg only exercise, combined leg-plus-arm followed by another leg only exercise to ensure there was no learning effect. In this study, the combined leg-plus-arm work involved adding arm work to maximal legwork. The results showed that adding arm work to maximal legwork increased VO_{2max} by 10% (an average of 3.09 l/min to 3.39 l/min). The increase in VO_{2max} could have been due to the increase in muscle mass and not a result of training. These findings support the earlier work [44, 59, 61] where only one subject was used. However it conflicts with other work [45] that reported no effect on $VO_{2\,max}$ with a larger sample size.

Rating of Perceived Exertion (RPE) during Arm and Leg Exercises

Several researchers have examined psycho-physiological responses to arm vs. leg exercise [65, 66, 69-72]. The first studies [66, 69] mainly dealt with leg exercise on a cycle. Borg et al. [63] developed a scale to measure effort sense which can be quantified by using rating of perceived exertion. The 15-point rating scale (Appendix D) is a categorical rating scale with rankings from 6 to 20; the rankings are related to perceived exertion and heart rate (60-200 beats/min). Using the scale, heart rate is approximately one-tenth of the exercise heart rate values for healthy, middle aged

men, and during an incremental exercise test the RPE should increase linearly with heart rate.

Borg believed that a subject's perception of effort was dependent upon cues from the musculature and circulatory system, in other words he believed there were local and central factors for RPE. The local factors being blood lactate accumulation and the central factors being VO_2, heart rate and ventilation [66, 69]. In terms of RPE for arm compared to leg exercise, Borg et al [66], found that the perception of effort was higher when exercising with the arms rather than legs. These findings relate to the fact that during arm exercise the heart rate, cardiac output, and ventilation are higher [52, 61, 63, 65-67]. In contrast Pandolf et al [65] found that RPE values were similar for arm compared to legwork during relative exercise intensities. Therefore, they stated that the critical variable for RPE as a predictor of exercise effort is the percentage of VO_2 peak [73].

Some researchers report that the oxygen uptake for arm-plus-leg exercise is equivalent to that of leg only exercise [45, 61, 74-76]. Therefore, it would be reasonable to suggest that the RPE for the two types of exercise would also be equivalent. However, studies [74, 77] have shown a difference in RPE. One of the earlier studies [77] conducted involved 3 subjects; RPE was recorded for arm-plus-leg and leg exercises at a maximal effort. It was found that the RPE values for the leg exercise were significantly greater than the exercise for arm-plus-legs [77]. Later work showed that RPE differences for the two types of exercises were only evident at higher intensities; at lower work rates the RPE values were the same [74]. This would suggest that at higher work rates there is more muscle mass recruitment in exercise

involving arm-plus-legs, therefore causing a subject to perceive the exercise as less stressful.

Cross-Country Skiing

One form of exercise that involves arms-plus-legs is cross-country skiing. Since a larger muscle mass is involved in skiing than in walking due to the use of arms to pull and push the ski poles, it is believed that VO_2 would be greater and the RPE would be less. Ronningen et al [78] compared the energy cost of walking on a hard snow covered level road with skiing on a level trail alongside the road. Each of the 6 subjects moved at a speed of 5 km/h. The results showed identical values for oxygen uptake although the subjects stated that skiing felt easier than walking. This could be explained by the larger muscle mass recruitment in skiing due to the upper body movement of the ski poles.

It has also been postulated [52] that the $VO_{2\,max}$ during skiing could be as high as 12% higher than during running. Meen et al [79] found that the energy expenditure of skiing uphill is higher than running uphill by 2.5 to 3 percent. In fact, cross-country skiers tend to record the highest maximal uptake in comparison to any other muscular activity [52, 62]. It is believed that this is due to greater muscle mass recruitment when skiing.

When measuring maximal oxygen uptake throughout the year in cross country skiers, it was found that there was a five percent drop from the end of the competition season to the end of the off season. For this reason in recent years cross-country skiers have been roller skiing, or ski walking in the off-season to help maintain their aerobic capacity. Interestingly, the popularity of ski walking in Europe has translated down to recreational skiers and general fitness programs. The sport of ski walking, an activity

involving walking with poles, was formally launched and called Nordic Walking in 1997. In the year 2000, 500,000 people in Finland participated in Nordic walking [22-24]. Today, almost one-quarter of the Finnish population uses Nordic walking as a form of fitness. The popularity of Nordic walking has spread over the whole of the Europe, and this past year the activity has hit the United States [22-24].

Pole Walking

Nordic Walking is similar to cross-country skiing except you are on foot, and the specially made poles exercise the upper body and reduce the strain on the lower extremity joints. It is important to remember that pole walking has been around for many years before Nordic Walking was ever introduced as a fitness exercise. First, as mentioned above, ski walking was used as an off-season training activity for cross-country skiers [52]. Second, for decades, walking poles have enjoyed a dedicated following of hikers and mountaineers to aid walking up and down hill, under the presumption that they increase safety over the uneven terrain, and ease the strain placed on the spine and lower extremities, give extra balance and reduce the shock placed on the body [26]. Third, pole walking has been used in the elderly and after orthopedic surgery as a form of assistive device.

Biomechanics of Walking with Poles

Nordic poles are increasing in popularity, and research on the use of poles by hikers is an ongoing research topic by biomechanists. According to past literature [14-16, 18, 20, 21, 26] the use of hiking poles reduces loading of the lower extremities and may thus reduce injuries over a long period of time. Jacobson et al [16, 18] compared lateral static balance with and without hiking poles while wearing and not wearing an internal frame backpack. The subjects (N = 15) were randomly assigned to

three conditions, no hiking poles, one hiking pole, and two hiking poles either with or without a load of 15 kg. One-minute trials were conducted three minutes apart. Subjects were instructed to balance on a stability platform for as long as possible during the one-minute trial, with their feet no more than 30 cm apart, and the hiking pole no more than 15 cm from the foot. The results found that two hiking poles enhanced balance and steadiness during hiking and reduced loading on the knees, hip and back.

It is believed that the poles are able to reduce the loading on the body because they increase the base of support and transfer some of the lower extremity loading to the upper body. There have been several studies [15, 21, 26] looking at the effect on the lower extremities when walking with hiking poles. Wilson et al, [26] studied thirteen healthy hikers having them complete four specifically ordered test conditions. Condition one acted as a control and involved the subjects walking across a six-meter level ground walkway at a self-selected speed. Condition two involved walking with the poles with no instruction. Condition three, involved walking with the poles and subjects were instructed to keep the lower tip of the pole angled backward at ground contact, and condition four involved walking with the poles keeping the lower tip of the pole angled forward at pole plant. To evaluate lower extremity performance during level ground walking with and without poles, Wilson et al [26] recorded the lower extremity joint angles and the angle of the pole when planted using a three-dimensional motion analysis system. The results supported previous work [15] stating that walking poles reduced the forces on the lower extremities during level walking when walking velocity was controlled. It was also suggested that changes in temporal, ground reaction force and knee joint kinetics indicate that the use of poles may be

beneficial for reducing loading in the lower extremities even at increased velocity on level ground.

Schwameder et al [21] investigated the effects of walking poles on knee joint forces during downhill walking. It is believed that high loads on the joints of the lower extremities cause the injuries and pain that occur during downhill walking [21]. The aim of the study was to determine external and internal loads on the knee joint during downhill walking with and without poles. Eight experienced male hikers took part in the study. Kinetic data was collected as each participatant walked down a 7-meter long, 1.2 meter wide and a decline of 25-degree. Each participant wore a backpack of mass 7.6 kg. It was discovered when walking with poles down a 25-degree decline that external peak forces to the lower extremities are reduced by 15%.

A number of studies [20, 80, 81] have identified the physical stresses of load carriage to develop strategies to minimize the discomforts for backpackers during prolonged hiking. Knight et al [20] investigated the use of walking poles to reduce the stressors for backpackers. Ten regular backpackers were recruited for the study. They were required to visit the laboratory on three occasions for testing. The testing involved two 60-minute walking trials on a treadmill at a 5-degree incline carrying a backpack and walking with and without poles. The two trials were presented in a counterbalanced order. Results showed that at the same treadmill velocity, subjects displayed a 6.7% longer stride length and a 6.3% lower stride frequency when walking with poles. The lower extremity joints and the trunk segment saw lower peak velocities, whereas the subjects displayed less knee flexion at heelstrike and greater knee range of motion during early stance weight acceptance. This indicates that use of

poles improved backpacking kinematics by causing the redistribution of muscular demand.

One limitation of all these studies is that they were carried out on a treadmill. The treadmill does not address the uneven terrain experienced during hiking and the interaction with the poles to the ground [20] .

Physiological Responses when Walking with Poles

Some researchers believe that the use of hiking poles can increase the metabolic responses to fitness walking in a safer way than walking with handheld weights, as they do not require the participant to swing the arms vigorously. A number of researchers [16, 18, 20, 27-31] have stated that there can be increases in oxygen consumption, as well as an increase in heart rate of up to 18 beats per minute when walking with poles. However, the literature shows conflicting results of the benefits of walking with poles. Some studies find that the individual is able to increase the benefits of the workout while reducing the rate of perceived exertion (RPE); others state that physiological responses (e.g. VO_2, and heart rate) remain the same even through RPE changes. There are many possible reasons for these discrepancies including the type of poles used, the self selected speed, and the walking terrain.

Treadmill Tests

During the same study by Knight et al [19] the subjects' RPE (using a 6-20 scale) at each ten minute intervals of the 60-minute trial, heart rate was measured at 2-min intervals, and oxygen uptake was measured every minute. RPE was lower throughout the test when using poles (10.6) compared to no poles (11.8). Heart rate was higher when using the poles by approximately 6 beats per minute, compared to

no poles. These results correspond with the research [74, 77] on combined arm-plus-leg exercise and can be explained by the added muscle mass recruitment when pole walking. Surprisingly, even through there was a difference in heart rate responses there was no difference in oxygen uptake when walking with or without poles while carrying a load. These findings support the work by other researchers [82, 83].

Jacobson et al [18] compared load carriage, heart rate, oxygen uptake, minute ventilation, energy expenditure and RPE during moderate graded treadmill walking with and without hiking poles. Their findings were slightly different than those of other researchers [19, 82, 83]. Twenty male subjects completed two random trials walking at 1.5mph for 15 minutes on a treadmill while carrying a 15kg load. The protocol was as follows: 1-minute at 10% grade, 2-minutes at 15%, and 20% grade and 10-minutes at 25% grade. The results showed RPE was significantly lower with hiking poles a similar finding as that of other researchers [17, 19, 82, 83]. No significant differences were seen in heart rate, oxygen uptake, ventilation and kcal for the two trials, therefore according to Jacobson et al [17, 18] the weight and use of the hiking poles does not increase energy expenditure but clearly reduces the perception of physical exertion.

Walking poles can be used in a manner that mimics the arm action of cross-country skiing. Using the arms in this manner could possibly increase the intensity of walking at any given speed and increasing upper body endurance. It is believed that the same physiological responses can be measured during pole walking due to the large muscle mass involved with the exercise. Porcari et al [29] tested 32 subjects, (16 males and 16 female). Using poles the subjects were required to complete two testing sessions, the first being a maximal oxygen uptake test. The second session required

the subjects to complete two twenty-minute sub-maximal walking trials on a level treadmill, one with poles the other without. The subjects were not required to carry a load as in other studies [18, 19] and the trial order was conducted randomly. During the tests, oxygen uptake, respiratory exchange ratio, energy expenditure, heart rate and RPE were measured every minute. Each subject walked at the same selected speed for each trial (at an average of 5-7 km). The results showed a metabolic steady state was achieved 3-5 minutes into the test, as the physiological responses reached a plateau. For all the variables, significantly greater physiological responses were measured when walking with poles. Heart rate was 15-21 bpm higher with the poles. RPE was higher when walking with the poles, this conflicts with the work of others [19, 82, 83] who reported that RPE was lower when pole walking. Porcari et al [29] found that the energy cost was approximately 23% (4.4 ml/kg/min) higher when walking with the poles compared to walking without the poles. This finding is greater than what was found by Rogers et al [30] who reported an increase of 12% in energy cost. These differences maybe due to the weight of the poles used for each study, and the speed at which the participants walked. Butt et al [84] found that the greatest differences in energy cost occurred when walking with poles at slower speeds on a dual action treadmill. Interestingly data from a study [85] conducted over a 12 week training period using two groups, one walking with poles and one without showed similar improvements in aerobic capacity, however the group walking with the poles achieved the benefits at a walking speed 0.8 km/h slower than the group with no poles. It has been shown by researchers [29, 84] that walking at the same speed can increase the intensity of the workout from 58% of heart rate max (HR_{max}) with no poles to 67% of HR_{max} with poles.

As mentioned earlier Rogers et al, [30] found a 12% increase in energy cost when exerstriding (a form of pole walking). Ten subjects completed two trials of 30-minute bouts of walking on a treadmill at 6.7 km/h (0% grade) with and without poles. The study measured energy cost, heart rate, RPE, RER. Significant differences were found in energy cost and RER. When walking with poles the energy cost and RER were higher. No difference was found in heart rate response and RPE when walking with or without poles.

Even though these studies [18, 19, 29, 30] showed metabolic benefits it could be suggested that these findings may not have occurred if the poles were used in other conditions such as varying terrain where the pole-ground interaction may allow more effective pole use compared to the treadmill [31]. Less research has occurred to test the physiological responses of walking poles in the natural environment of the sport, and majority of the studies [18, 19, 29, 30, 82-84] have been in exercise physiology laboratories due to the fact that it is easier to monitor responses and control environment conditions.

Field Testing

Even though other conditions such as varying terrain, where the pole-ground interaction may allow more effective pole use compared to the treadmill only two studies where found that involved field-testing, [17, 31] The two-field studies involved extremely different techniques; Church et al [31] used Nordic poles on a level surface with no load, whereas Jacobson et al [17] used hiking poles on a graded surface while carrying a backpack.

Church et al [31] compared the energy expenditure of walking with and without Nordic poles in the field. A total of twenty-two subjects (11 men, 11 women)

completed two walking trials of 1600m on a 200m track, one with Nordic poles the other without. The trials were administrated in a randomized and counterbalanced manner on the same day. Every 200 meters, heart rate, RPE and lap time was recorded. Participants were asked to keep the time to complete the 200m laps the same for each trial. The results supported other research showing that walking with poles significantly increased oxygen consumption by 20%, caloric expenditure by 19-21%, and heart rate [29, 30]. Church et al, found no significant difference in RPE, and the time to complete the 1600-meters. It was concluded that Nordic walking can significantly increase oxygen and caloric expenditure without increasing the perceived exertion. These findings contrasted with those of Porcari et al [29] who found an increase in RPE of 1.5 units when using poles.

Although Church et al. [31] found that Nordic poles caused a significant elevation in heart rate (6%) it was smaller than that found by other researchers [29, 30], who found differences of up to 16%. The increase in oxygen consumption (20%) in the Church et al [31] study is a lot greater than that found by Rogers et al, [30] who found a 12% increase. These differences could be explained by the speed at which the subjects walked. In the study of Roger et al [30] the participants walked approximately 1 km/h faster than the participants in the study by Church et al [31].

Jacobson et al [17] compared heart rate, and ratings of perceived exertion during a steep ascent and decent while wearing a backpack with and without poles. Eleven subjects carried out two randomized trials of continuous 50-meter descents and ascents on a 40-degree slope with and without poles; there was a 15 second data collection stop between trials. A metronome set at 72 beats/min controlled the step frequency and pace for each trial. It was found that heart rate was significantly higher

with poles, but only for the first ascent. For the second ascent and the two descents no difference was found. RPE was significantly lower on all trials when using the poles. These findings disagree with previous studies [29-31]. The lower perceived exertion may be due to the added stability and reduced loading given by the poles.

Summary

It is clear that walking is a popular form of LTPA for weight control in all levels of healthy adults. However in order to reach the Healthy People 2010 objectives more work is needed to promote new and different forms of exercise [1]. It has been shown that by simply adding more arm action to a brisk walk, an individual can increase the intensity of the workout without increasing their rating of perceived exertion. Many individuals may not comply with physical activity recommendations if the perceived exertion is too high. Therefore, an activity that is perceived as being less strenuous may yield greater health benefits, and we would be closer to reaching the Healthy People 2010 objectives.

Cross-country skiing can produce the highest measures of both maximal and sub-maximal oxygen uptake without an increase in perceived exertion [52, 62]. This is believed to be due to the larger volume of muscle mass recruitment during the exercise. Numerous researchers [16-19, 27, 29-31] have shown that physiological responses such as VO_2, heart rate, ventilation and energy expenditure can be increased by adding poles to a walking prescription. Interestingly, the rating of perceived exertion is decreased or maintained the same when speed remains constant. However, most of these studies have taken place on a level or graded treadmill, which does not account for the pole ground interaction and uneven terrain that occurs in the natural environment. There are no studies to date that have researched the performance

effects of poles in terms of speed/time due to the fact that speed has been kept constant in all studies. Research in blood lactate accumulation has been neglected in this field of study. Further research on hiking poles is needed to resolve the conflicts found in the literature and elucidate the potential benefits.

CHAPTER 3

MANUSCRIPT

Abstract

PURPOSE: The primary purpose of this study was to compare performance when hiking with and without poles during a maximal effort mountain ascent. In addition, the study determined if there were differences in physiological responses, such as heart rate, estimated energy expenditure, and blood lactate accumulation.

METHODS: 15 physically active men and women (mean age 29±6) hiked with and without walking poles up a 4.42 km trail (426m elevation gain) in a counterbalanced order. The trail was measured using a GPS device. Performance was determined by the time taken to reach the top of the mountain. In addition, differences in physiological variables including heart rate (HR), estimated energy expenditure (EE), and blood lactate (LA) accumulation were measured.

RESULTS: When hiking with or without poles, there were no statistically significant differences found for any of the outcome variables. Time-to-completion (53.24 ± 5.31 vs. 52.74 ± 4.47min) and blood lactate (LA) accumulation (6.23 ± 2.5 vs. 7.23 ± 3.88mmol/l) were similar, with and without poles, respectively. Similarly, no differences were seen for HRmax, average HR, and estimated EE, all variables displayed by the Polar heart watch.

CONCLUSION: In conclusion, performance and physiological responses do not appear to differ when hiking with and without poles on a 4-km mountain ascent. However the subjects reported that the poles reduced the lower back and lower extremity pain the day following the hike. Even though no significant effect was found in the rating of perceived exertion between the two conditions (poles vs. no

poles, respectively) 14 out of 15 subjects indicated in a follow up interview that they felt the poles made the effort easier.

Key Words: Pole walking, Heart Rate, Energy Expenditure, Blood Lactate, Rating of Perceived Exertion.

Introduction

Physical inactivity is a major health problem within the United States of America [1]. A lack of time and the shortage of affordable fitness facilities are frequently cited as barriers to physical activity [2]. In recent years, walking has been suggested as a feasible exercise mode for individuals who need to increase their physical activity. It is a low impact activity, inexpensive and it can be carried out almost anywhere at anytime. Regular walking can lead to a number of health benefits such as increased aerobic capacity, decreased blood pressure, and enhanced glucose control. Walking can also relieve stress and improve a person's state of well being [3-10].

Walking is a feasible starting exercise for previously inactive individuals, but as fitness levels improve walking speeds must increase in order to see additional improvements. This means that individuals may need to engage in race walking or jogging in order to achieve a cardiovascular training effect. However, race walking is a skill that is not easily acquired, and jogging can lead to problems such as lower extremity injuries [11-13].

An alternative exercise mode is walking with poles. This provides more of a total body workout but avoids the high impact forces of jogging. Walking with poles is not new; in fact, it has been around for decades. Hikers and mountaineers have long used walking poles to aid in going up and down hill, under the presumption that they

increase safety over the uneven terrain, ease the strain placed on the spine and lower extremities, enhance balance, and reduce the impact forces on the body [14-21].

Pole walking originated in Finland and was initially practiced in the 1930's by the Finnish cross country skiers who used pole walking as a form of summer endurance training in order to keep fitness levels high during their off season. Due to the popularity of pole walking, the sport of Nordic walking was launched in 1997. Nordic walking is cross-country skiing except on foot. In the year 2000, 500,000 people in Finland participated in Nordic walking [22-24].

When walking with poles it is important to have the correct technique (figure 2). One should walk naturally except steps should be lengthened by around 5% compared to the normal stride. The shoulders should be relaxed with the hands and poles close to the body. A forward stride is taken with one foot and the opposite arm; the pole is planted and then the arm swings backwards as the other arm and leg move forward. The poles should be adjusted to the correct height, making sure that when the poles are planted the elbow is bent at a 90° angle [22, 25]. Today, almost one-quarter of the Finnish population use pole walking as a form of fitness. The popularity of pole walking has spread across Europe and it is growing in popularity in the United States [22].

Biomechanists have conducted research on the use of hiking poles. The use of hiking poles has been shown to reduce loading of the lower extremities and therefore, may reduce injuries over a long period of time [14-21, 26, 86]. Walking poles have not only been studied for the beneficial effects they have for reducing lower extremity loading while hiking, but also for the increase in physiological responses while fitness walking in a safer way than walking than walking with handheld weights, since they

Figure 2: Shows the pole technique when hiking with two poles.

do not require the participate to swing the arms in a vigorously action [27].

Researchers [17, 19, 27-31] have stated that pole use can be increase oxygen consumption by 12-23%, and increase heart rate by up to 18 beats per minute. However, the literature shows conflicting results of the benefits of walking poles. Some [19, 29, 31] believe the individual is able to increase the intensity of the workout while reducing/increasing the rating of perceived exertion (RPE); others state that physiological responses such as oxygen uptake, and heart rate remain the same even through RPE changes [17, 18, 30].

A limitation of past research on pole walking is that most of these studies have used treadmills, which do not account for the pole-to-ground interaction and uneven terrain that occurs in the natural environment [19, 31]. Only two studies have examined the use of hiking poles in a field setting [17, 31]. The first [31] used Nordic poles on a level surface with no load, whereas the second study [17] used hiking poles on a graded surface while carrying a backpack.

Purpose

No studies to date have examined the effects of hiking poles on maximal exercise performance in a field setting. Thus, the purpose of this study was to determine the performance differences when walking with and without poles during a 4-Km maximal effort mountain climb. In addition, the study determined if there were differences in physiological responses such as heart rate, estimated energy expenditure, and blood lactate accumulation.

Hypotheses

Based on previous pole walking research and its effect on performance and physiological responses when walking with and without poles, we hypothesize that:

1. There will be a performance difference in the amount of time taken when walking with and without poles during a maximal effort mountain ascent.
2. There will be differences in physiological responses, such as heart rate, energy expenditure and blood lactate accumulation when walking with and without walking poles during a maximal effort mountain ascent.

Methods

Participants

The participants included fifteen physically active, non-smoking adults (7 males and 8 females) between the ages of 18-40 (mean age of 29 $\pm$ 6 years). The participants were familiar with pole hiking and hiked an average of 4 times per year. All participants were recruited by advertisement and word-of-mouth from the University of Tennessee student body and surrounding community. Participants were

excluded from the study if they reported being pregnant, having high blood pressure, having cardiovascular or pulmonary diseases, or recent orthopedic problems.

Testing Protocol

Testing was performed both in the Applied Physiology Laboratory in the Health, Physical Education, and Recreation Building, as well as out in the field. The field-testing was conducted on the Rich Mountain trail, in the Great Smoky Mountain National Park. The trail was 4.42 km with an elevation gain of 426-meters. The starting point was at Cades Cove and the ending point was at Indian Grove Gap (Appendix C).

After the initial telephone interview, each participant was required to complete four days of testing. On the first day, each participant visited the Applied Physiology Laboratory on the University of Tennessee campus. Upon arrival at the laboratory, the participants were asked to read and sign an informed consent form approved by the University of Tennessee Institutional Review Board (Appendix A). Any questions regarding the informed consent form or the study were encouraged from all participants. In addition, participants filled out a health history questionnaire (Appendix B) to assess their health status. This served as a screening tool to help ensure that the participant had no diseases or orthopedic problems that would be contraindications to maximal exercise.

Anthropometric variables were measured to determine the participant's body mass index (BMI). Body mass index was calculated by dividing the weight in kilograms by height in meters squared [87].

Maximal oxygen uptake (VO_{2max}) was measured using a metabolic measurement system (Parvo-Medics True Max 2400). The metabolic measurement system

measured the participant's expired air via a Hans-Rudolf 2-way non-rebreathing value, which was placed in the participant's mouth, with a tube connected to the measurement system. The participant wore a nose clip to ensure all expired air was measured during the test. The protocol used to measure the maximal oxygen uptake was the Balke Super Standard: Constant Speed Treadmill Test [86]. This test required the participant to walk on the treadmill at a constant speed of 6.1 km at a 4% grade. After each minute of the test, the grade of the treadmill was increased by 2%. Once a 20% grade was reached, the time of each stage increased to 2 minutes. The grade continued to increase until the participant reached exhaustion. The maximal oxygen uptake test was carried out at a time convenient to the participant; however, they were instructed to abstain from exercise for at least four hours prior to the test. The highest minute VO_2 value recorded during the test was considered the VO_{2max}.

Heart rate was measured each minute throughout the test using a Polar heart rate monitor. An electrode belt was strapped around the chest just below the breast and the heart rate watch was placed on the wrist. A blood sample was taken within 3 minutes post-exercise, using a finger stick to collect 100ul of blood in a tube. Blood lactate was analyzed in the Applied Physiology lab by a trained technician using an automated lactate analyzer (YSI 3100).

After the maximal oxygen test, each participant was instructed on the proper technique for using walking poles and practiced the technique on Rich Mountain. The purpose of the hike was to gain an initial understanding of the trail conditions before the field-testing began. Pole technique was important in this study, since an incorrect technique would have affected the results.

On two subsequent days the participants met at an arranged location where they were instructed to hike at a maximal effort from trailhead to the mountaintop. One half of the participants were randomly assigned poles on day one, on the second day the treatment was switched. Each participant was instructed to walk up the mountain trail with or without hiking poles at a maximal effort. The participants were informed that the effort was a maximal effort time trial but they were not to run. Participants started at 5-minute intervals. The time taken to walk the trail was measured using a stopwatch. During the trail ascent, heart rate was measured each minute using a Polar S610i downloadable heart monitor. Once the participant reached the top of the trail, a fingertip blood sample was collected 3-minutes post-exercise, for the purpose of determining blood lactate levels. Each blood sample was put into a tube, marked and placed on ice to be analyzed in the laboratory within 24 hours of the test. Participants were also asked to rate their perceived exertion using the Borg 15 point scale on completion of the trail (Appendix D) [66, 69, 72]. Participants returned to the bottom of the mountain trail on foot at a relaxed pace, after a 15-20 minute rest at the top of the trail.

Statistical Analyses

Statistical analyses were completed using SPSS 13.0 version for Windows (SPSS Inc., Chicago, IL). Initially, a multivariate repeated measures analysis was carried out to show the effect when comparing order with blood lactate, time-to-completion, HRmax, average heart rate, energy expenditure and RPE. The same analysis was carried out comparing gender with the variables mentioned above. Paired t-tests were used to analyze heart rate max, average heart rate, blood lactate, and energy expenditure (Kcal). The rating of perceived exertion (RPE) was analyzed

using Wilcoxon matched pairs, (a non-parametric test) due to the scale being ordinal. In this analysis, the sizes of the differences are ranked. Statistical significance was determined using an alpha level of 0.05.

Results

Physical Characteristics

Descriptive characteristics of the participants are shown in table 1. The participants had a mean age of 29 $\pm$ 6 years, height (in) of 68.93 $\pm$ 3.09, weight (kg) 70.04 $\pm$ 10.05, a BMI of 23.47 $\pm$ 2.77, VO_{2max} (ml/kg/min) of 46.25 $\pm$ 8.40, HR_{max} of 186 $\pm$ 12 and peak exercise blood lactate (mmol/l) of 10.79 $\pm$ 3.54 at 3-minutes post-exercise.

Order and Gender

A multivariate repeated measures analysis showed that there was no significant effect when comparing trial one and trial two. No significant order effects were seen for blood lactate accumulation, time-to-completion, HR_{max}, average HR, energy expenditure and RPE. The same was true for the repeated measures analysis of gender and the above mentioned outcome variables at an alpha level 0.05.

Table 1: Descriptive Characteristics of Participants

	Mean	SD
Age (years)	29	6
Height (inches)	68.93	3.09
Weight (kg)	70.04	10.05
BMI (kg/m2)	23.47	2.77
VO_{2max} (ml/kg/min)	46.25	8.4
HRmax (bpm)	186	12
Blood Lactate (mM)	10.79	3.54

BMI = Body mass index
VO_{2max} = Maximal oxygen uptake
HRmax = Maximal heart rate

Performance Results

The performance of each participant was determined by the time taken to finish the 4.42 km trail and the blood lactate accumulation. When all the participants' times and blood lactate accumulation values were examined, it was found that there was no significant difference between hiking with and without poles (p = .570 and p = .347 respectively) (Table 2 and 3).

Figure 3 shows the similarity of the heart rate responses over 5-minute intervals for the two conditions walking with and without poles Figure 4, and 5 shows the similarity of time-to-completion of the trail and blood lactate accumulation respectively for the two conditions walking with and without poles.

Table 2: Mean and Standard Deviation Values for all Performance and Physiological Variables

	With Poles	Without Poles
Lactate (mM)	6.2 ± 2.5	7.2 ± 3.9
HRmax (bpm)	181 ± 13	180 ± 12
HRavg (bpm)	160 ± 16	159 ±15
Time to Completion (min)	53.2 ± 5.3	52.7 ± 4.5
Estimated EE (Kcal)	889 ± 235	875 ± 211

Subjects: 15

Table 3: Paired T-tests for all Performance and Physiological Variables

	Mean difference ± SD	t	Sig (2-tailed)
Lactate (Poles vs. No Poles)	-1.00 ± 4.0	-0.972	0.347
HRmax (Poles vs. No Poles)	0.6 ± 6.69	0.348	0.733
HRavg(Poles vs. No Poles)	1.00 ± 10.2	0.431	0.673
Time to Completion (Poles vs. No Poles)	0.5 ± 3.3	0.581	0.570
Estimated EE (Poles vs. No Poles)	14 ± 110	0.481	0.638

df: 14, sig $p<0.05$

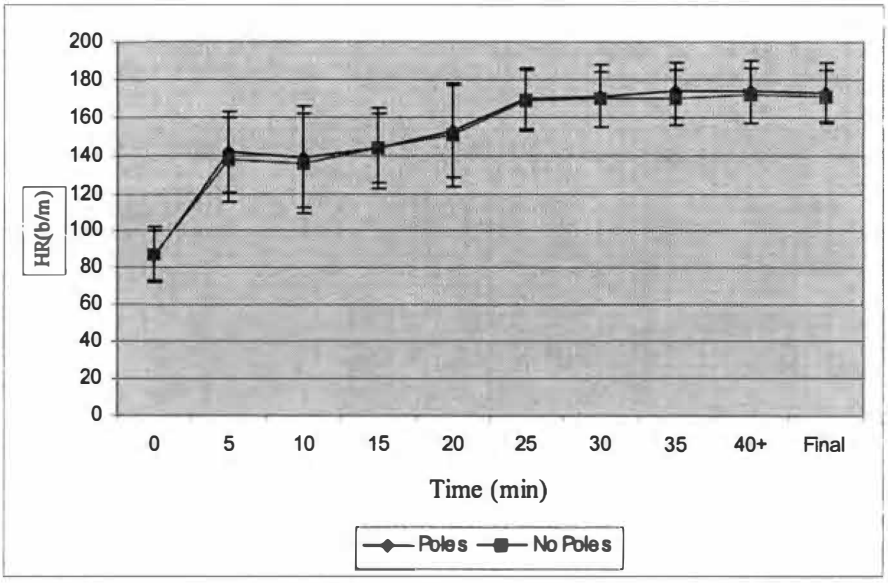

Figure 3: Heart Rate Responses versus Time during hiking with and without Poles

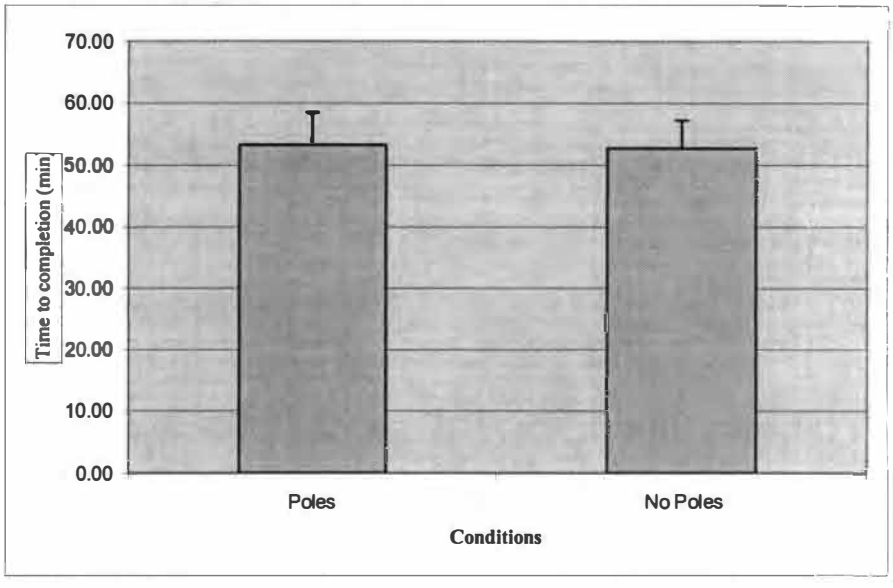

Figure 4: Time-to-Completion of the Trail with and without Poles (mean ± SD)

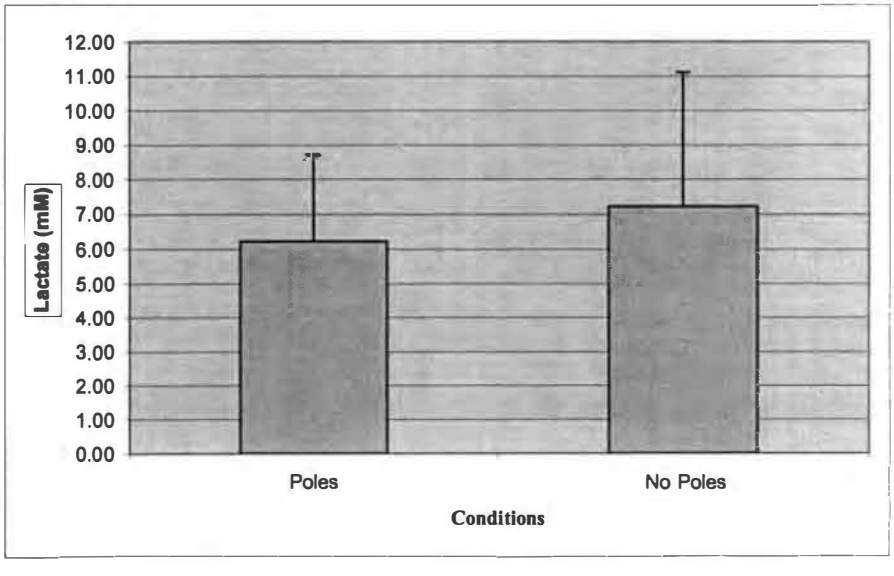

Figure 5: Blood Lactate (mM) accumulation when hiking with and without Poles (mean ± SD)

Physiological Responses

The physiological responses of each participant were determined by heart rate max (HR_{max}), heart rate average (HR_{avg}), estimated energy expenditure (Kcal), and rating of perceived exertion (RPE). Paired t-tests were used to analyze HR_{max}, HR_{avg}, and estimated energy expenditure. There were no significant differences ($p = .733$, $p = .673$ and $p = .638$ respectively). These findings are shown in tables 2, 3 and figures 6 and 7. RPE was analyzed using the Wilcoxon matched pairs, non-parametric test due to its ordinal nature, and no significant difference was observed ($p = .059$). These findings are shown in tables 4, 5. Figure 8 shows the mean similarity and stand deviation for ratings of perceived exertion (RPE) when hiking with and without hiking poles.

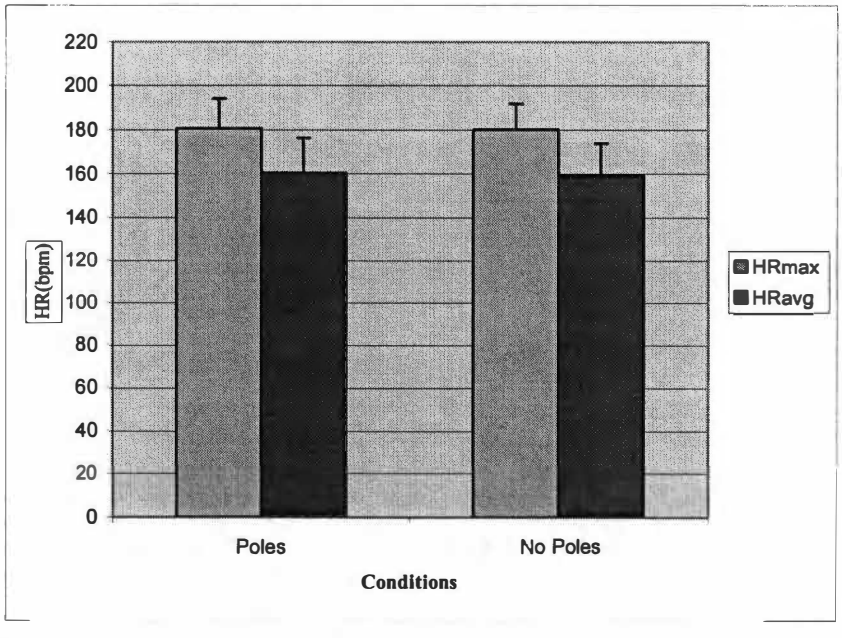

Figure 6: Maximal Heart Rate and Average Heart Rate when hiking with and without Poles (mean ± SD).

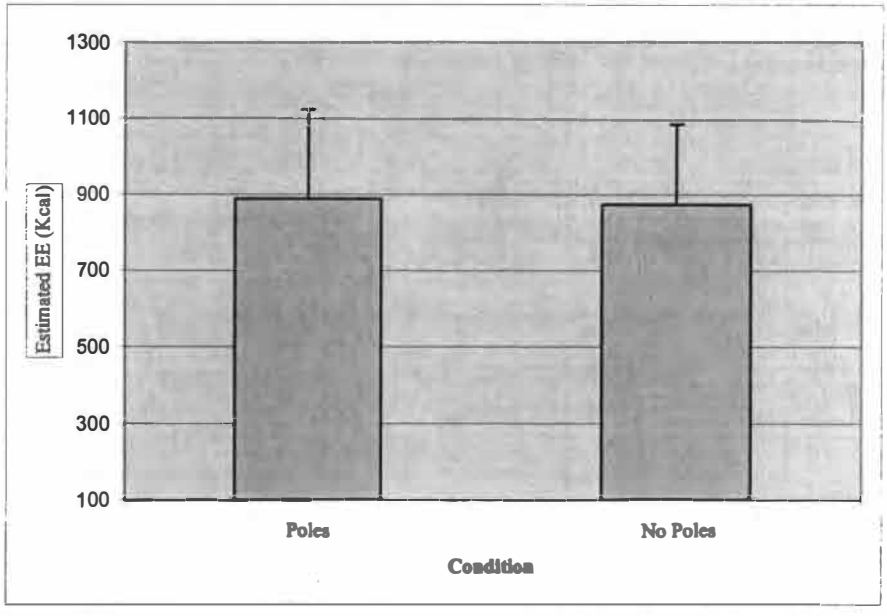

Figure 7: Estimated Energy Expenditure (kcal) when hiking with and without Poles (mean ± SD).

Table 4: Wilcoxon Signed Ranks, for RPE when comparing Poles and No Poles

		N	Mean Rank	Sum of Ranks
RPE (Poles vs. No Poles)	*Negative Ranks*	3a	5.17	15.5
	Positive Ranks	9b	6.94	62.5
	Ties	3c		
	Total	15		

a. RPE: without poles < with poles
b. RPE: without poles > with poles
c. RPE: without poles = with poles

Table 5: Statistical Values for the Wilcoxon Signed Ranks (a non-parametric test) comparing RPE with Poles and no Poles

	RPE
Z	-1.888a
Asymp. Sig. (2-tailed)	0.059

a. Based on negative ranks

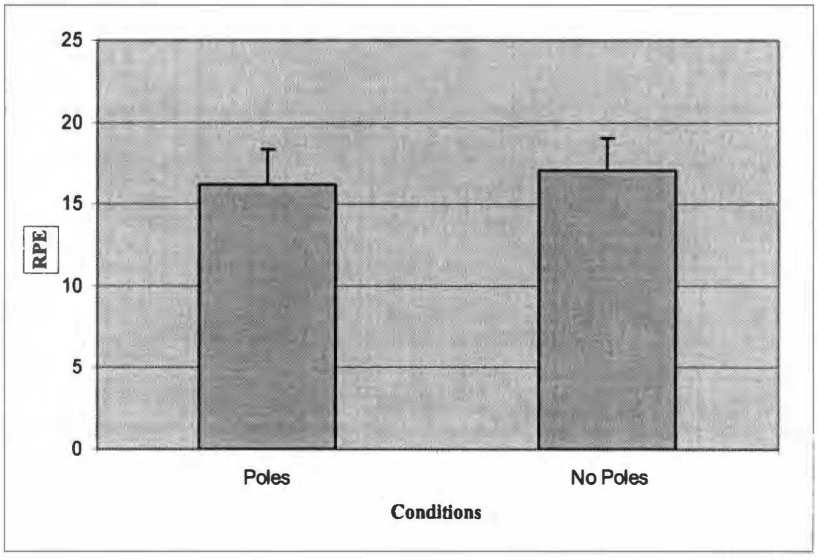

Figure 8: Rating of Perceived Exertion when hiking with and without Poles (mean ± SD).

Discussion

The main findings of this study was that the use of hiking poles had no effect on time-to-completion, blood lactate accumulation, HR_{max}, HR_{avg}, estimated energy expenditure (kcal) or RPE, during a maximal effort mountain ascent.

The findings of this study in terms of heart rate and energy expenditure are at variance with the findings of other researchers [19, 29-31] who found a significant increase in oxygen uptake (VO_2), heart rate (HR), and energy expenditure when walking with poles. However, the studies of Porcari et al [29] and Rodgers et al [30] required their subjects to walk with poles on a motor driven treadmill. Church et al, [31] found an increase of approximately 20% in oxygen uptake when walking with poles. However the subjects were required to walk on a level 200m track. There were no extreme inclines as in the present study.

The findings of this study does support earlier work by Jacobson et al [17, 18] who found no significant increase in HR, VO_2, VE and energy expenditure when walking with and without poles. Jacobson et al [17, 18] found no significant differences in both treadmill and field tests. Both of these studies required subjects to walk with hiking poles and a backpack load. The differences between the findings of the present study and work by Jacobson et al [17, 18] compared to other researchers [19, 29-31] could have been due to the poling technique. When using hiking poles, there is not as much of an exaggerated arm action. The exaggerated arm swing used in earlier studies [29-31] could have generated the greater increases in physiological responses. The objective of the hiking pole technique is to use the poles to reduce stresses and exertion during the hiking process. Thus the additional upper body

involvement used to propel the sticks may have canceled out the reduced work of the lower extremities. This would support work carried out by researchers on combined leg and arm work [45, 61, 62] who stated that central physiological responses did not change when arm actions were added to leg work.

The earlier studies that showed significant increases in HR, VO_2, and VE [29-31] used Nordic poles and required the participants to walk on hard surfaces. Therefore the pole push off may be more exaggerated than on uneven terrains where the poles seem to be used more for balance and reducing lower extremity loading without affecting physiological responses.

In terms of ratings of perceived exertion (RPE), the findings of this study support earlier work by researchers [30, 31] who found no change in RPE when walking with and without poles. Even though the present study supported work of Jacobson et al [17, 18] in terms of HR, VO_2, VE, and energy expenditure, it did not support the findings on RPE. Jacobson et al [17, 18] found that RPE decreased when walking with the poles. They suggested that the decreased rate of perceived exertion could have been due to the added stability provided by the poles. The reason the RPE in the present study may not have changed between the two conditions walking with and without poles could have been due to the intensity at which the participants worked during each condition. In both the pole and no pole conditions the participants worked at approximately 88-89% of their maximum heart rate. The participants in the present study were asked to hike at a maximal effort under time trial conditions. Interestingly, even though the results of RPE were not significantly different, during a follow up question to all participants asking if they found the hike to be easier with the poles or without, 14 out of the 15 participants reported that it was easier with the

poles. They stated that the poles reduced the lower back and leg pain the day after the hike. Thus, they were able to walk more upright with the poles and did not have to worry about balance when crossing streams. This would suggest that during hiking the poles do help to reduce lower extremity loading, supporting earlier biomechanical research [16, 20, 26], even if central physiological responses remained the same.

The non-significant differences in physiological responses in this study may have also been limited due to the speed at which the participants hiked up the mountain trail. Earlier research [29, 31] found that when the participants walked at slower speeds on level ground the physiological differences between poles and no poles were greater than when participants walked at a greater speed. Porcari et al [28, 29] and Church et al [31] found that using poles increased the energy cost of level walking by 20 and 23% respectively. In contrast, Rodgers et al [30] only elicited a 12% increase in VO_2. Porcari et al [29] and Church et al [31] indicate that this difference may have been due to the fact that the participants in the study by Rodgers et al [30] walked approximately 1 km/h faster than their participants.

To our knowledge this study was the first to examine the performance effects of poles during a maximal effort hike. Performance was determined by time-to-completion and blood lactate accumulation. This study showed no significant effect on performance when walking with and without poles. The subjects were not trained with the arms so they may not have the ability to make a significant contribution to the total work with their arms. The similarities in blood lactate accumulation during the two conditions support earlier work [45] on leg, arm and combined leg plus arm exercise, which found that all combinations of exercise give similar blood lactate readings.

A major limitation of the present study is sample size. It could be suggested that with a larger sample size, significant differences might have been found. When carrying out a sample power analysis on both RPE and lactate it was found that in order to see significance we would have needed between 40 and 126 subjects. Furthermore, the lack of environmental control could have affected the present results. Over the two test days there was a temperature difference of approximately 20-degrees. This difference could have affected the heart rate responses of the participants during the hike. Therefore, it could be suggested that more strict environmental controls could have resulted in physiological and performance differences. However, this would have defeated the object of the study being carried out in the sport's natural environment.

Further research is needed in the area of hiking poles to determine the effects on performance and physiological responses. One suggestion would be to study the physiological response when carrying a load. Jacobson et al [17] in an earlier study examined this question. However, the trail distance was short, and different results may be found with a longer trail, which would impose more challenges on hiking. The present study was carried out on a trail that was 4.42 km long with an approximate elevation gain of 426-meters. Most of the participants who took part in this study were familiar with hiking and were young, active individuals. It would be interesting to study an older population to see if the same results could be found as in this study or whether the poles would benefit the older population, resulting in increases in performance and physiological responses when hiking with poles. Also it would be interesting to examine the effect training had on pole use. Training may enhance the role of poles in performance.

In conclusion, the present study indicates that the use of poles when hiking does affect performance or physiological responses to a steep 4.42km trail at maximal effort. However, it may be suggested that there is a psychological benefit from using the poles when hiking to reduce the lower back and leg pain felt the day after the hike. However it is recommended that this last observation be tested to determine the reliability of the effect.

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APPENDICES

Appendix A:

Informed Consent

INFORMED CONSENT FORM

Investigator: Rachel Duckham

Address:
The University of Tennessee
Department of Health and Exercise Science
1914 Andy Holt Ave.
Knoxville, TN 37966

Telephone: (865) 974-8768

Purpose
You are invited to participate in a research study. The purpose of the study is to determine the physiological responses of hiking poles during a trek up a mountain trail. If you give your consent, you will be asked to perform the testing stated below. This testing will take approximately (3-4) hours on four separate days. You will first be asked to complete a health questionnaire to determine your health status. Height, weight and maximal oxygen uptake will be measured in the Applied Exercise Physiology Lab. On a subsequent day your maximal oxygen uptake will be measured asked. On the three field-testing days you will be asked to report to room 317 in HPER and we will transport you to Rich Mountain.

Testing
1. Height and weight will be measured.
2. Maximal oxygen uptake (VO2 max), which is the maximum amount of oxygen, your body can take in and use per minute. The test can be done at any time of the day; however, you are asked to abstain from exercise for four hours before the test. For this test a metabolic measurement system will be used to measure the amount of oxygen and carbon dioxide you expire during exercise. You will breathe through a mouthpiece with a nose clip to prevent nasal breathing. You will walk on a treadmill at a speed of 3.8mph with a starting incline of 4%. Every minute the grade of the treadmill will be increased by 2%, once a 20% grade is reached the stage will last for 2 minutes until you are too tired to continue.
3. Heart Rate will be monitored during each trial using a heart rate monitor. An electrode will be strapped around your chest and you will wear a watch that will read and record your heart rate.
4. Before the field-testing begins you will be instructed on the correct technique of using hiking poles.
5. For the field testing you will be asked to report to an arranged location on two separate days. You will be asked to hike up the Rich Mountain trail in the Great Smoky Mountains as fast as you can either with or without hiking poles. The Rich Mountain trail is 2.75 miles with an elevation gain of 1400 feet. Throughout the test your heart rate will be measured. Once you reach the top of the mountain trail you will have your blood lactate tested within 3 minutes. A few drops of blood (100μl) will be collected in a tube using a finger stick. The blood will be analyzed in the Applied Physiology Lab on return to Knoxville. You will return to the bottom of the mountain trail by foot after a 15-20 minute rest after test completion.

6. During the test you will be supplied with water from volunteers who will be located at mile markers on the trail.

Potential Risks
The risks associated with exercising are very slight in a healthy population during maximal exercise. These risks include abnormal blood pressure responses, musculo-skeletal injuries, dizziness, shortness of breath, hypothermia, and in rare cases, sudden death. If you experience any abnormal feelings during this study you should inform one of the volunteers on the trail, and stop exercising immediately. The volunteers will then recommend that the participant seek medical care on his/her return to Knoxville. In an extreme emergency a volunteer will drive the participant to Blount Memorial hospital or call 911 to request Life Star assistance. The risks associated with the trail climb include; uneven terrain due to loose stones and tree branches which may cause falls, or twisted ankles. There is also a risk associated with wildlife, in rare instances you could experience snakebite or be attacked by a bear.

Benefits of Participation
From the results of this study you will be told your maximal oxygen uptake (VO2 max), which is an indicator of cardiorespiratory fitness, your heart rate values over a 2.75 mile mountain hike and your blood lactate accumulation after a maximal effort hike. You will also gain knowledge of using hiking poles.

Confidentiality
The information obtained from these tests will be treated as privileged and confidential and will consequently not be released to any person without your consent. However, the information will be used in research reports and presentations. At no time will your name or any other identity be disclosed.

Contact Information
If you have questions at any time concerning the study or procedures, you may contact myself. If you have questions about your rights as a participant, please contact the Research Compliance Services of the Office of Research at (865) 974-3466.

Right to Ask Questions and Questions and to Withdraw
You are free to decide whether or not to participate in this study and free to withdraw from the study at any time.

Before you sign this form, please ask questions about any aspects of the study, which are unclear to you.

Consent
By signing, I am indicating that I understand and agree to take part in this research study.

_____ _____

Your Signature Date

_____ _____

Researchers Signature Date

Appendix B:

Health History Questionnaire

HEALTH HISTORY QUESTIONNAIRE

NAME_____ DATE_____

DATE OF BIRTH_____ AGE_____

ADDRESS_____

_____

PHONE NUMBERS
(HOME)_____(WORK)_____

e-mail address:_____

When is the best time to contact you? _____
Please answer the following questions. This information will only be used for research purposes and will not be made public. Please answer the following questions based on physical exercise in which you regularly engage. **This should not include daily work activities such as walking from one office to another.**

1. Do you regularly engage in exercise? Yes/No If yes, please describe.

_____

_____

2. On average, how many times per week do you engage in exercise?

0_____1_____2_____3_____4_____5_____6_____7_____

3. On average, how long do you exercise each time?

0-19 minutes_____20-40 minutes_____ more than 40 minutes_____

4. How long have you been exercising at this level?
   Less than 6 months _____
   6 – 12 months _____
   1 – 2 years _____
   3 or more years _____

5. How many times per year do you hike in the mountains either in this area or other states in the United States?

0-2 times: _____ 2-4 times:_____ more than 4 times: _____

MEDICAL HISTORY

Past History:

Have you ever been diagnosed with the following conditions? Please check the appropriate column.

	Yes	No	Don't Know
Rheumatic Fever	( )	( )	( )
Heart Murmur	( )	( )	( )
High Blood Pressure	( )	( )	( )
Any heart problem	( )	( )	( )
Lung Disease	( )	( )	( )
Seizures	( )	( )	( )
Irregular heart beat	( )	( )	( )
Bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Asthma	( )	( )	( )
Kidney Disease	( )	( )	( )
Liver Disease	( )	( )	( )
Severe Allergies	( )	( )	( )
Orthopedic problems	( )	( )	( )
Hyper- or Hypothyroidism	( )	( )	( )
HIV, Hepatitis, or other Blood borne diseases	( )	( )	( )
Heparin Sensitivity	( )	( )	( )

Present Symptom Review:

Have you recently had any of the following symptoms? Please check if so.

Chest Pain	( )	Frequent Urination	( )
Shortness of Breath	( )	Blood in Urine	( )
Heart palpitations	( )	Burning sensations	( )
Leg or ankle swelling	( )	Severe headache	( )
Coughing up blood	( )	Blurred vision	( )
Low blood sugar	( )	Difficulty walking	( )
Feeling faint or dizzy	( )	Weakness in arm	( )
Leg numbness	( )	Significant emotional problem	( )

Do you smoke? Yes/No If yes, how many per day? _____

Are you taking any prescription, over-the-counter or herbal medications at this time? Yes/No

If yes, please describe: _____

On average, how many alcoholic drinks do you consume per week?

_____

Can you walk 3 miles continuously without pain or discomfort? _____

OTHER INFORMATION

Whom should we notify in case of emergency?

Name _____

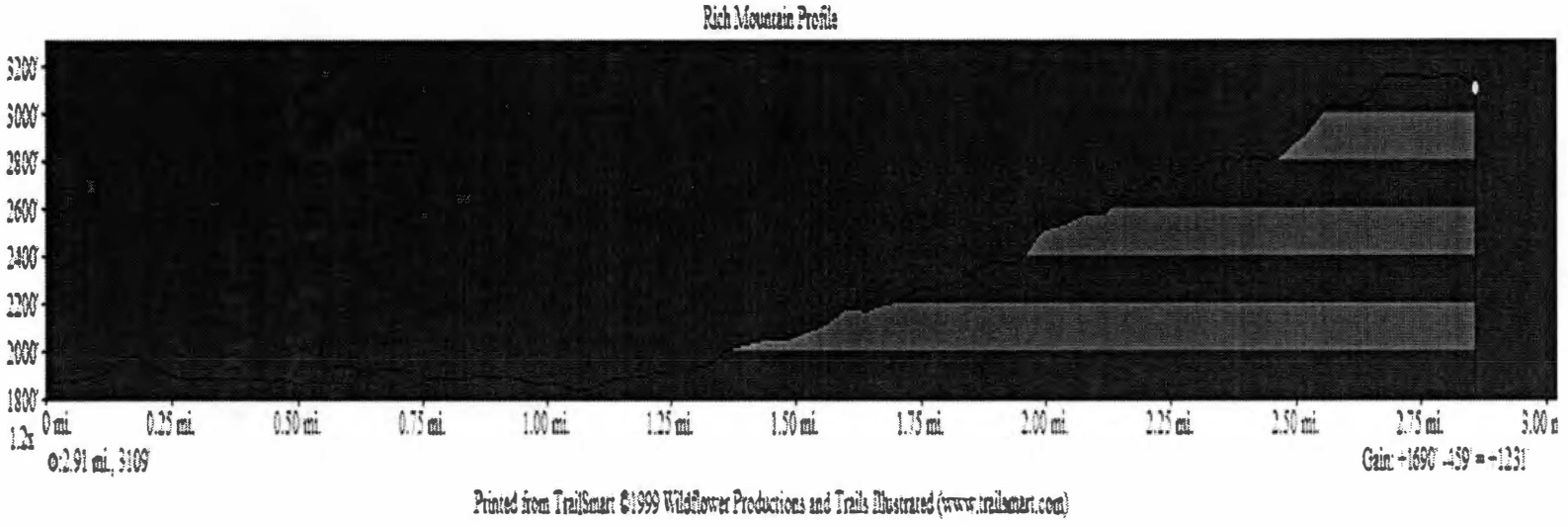
Address _____

Phone # _____

Appendix C:

Rich Mountain Trail Profile

Rich Mountain Trail Profile



Appendix D:

Borg's 15 Point Scale Rating of Perceived Exertion

Borg Scale of Rating of Perceived Exertion

6	
7	**VERY, VERY LIGHT**
8	
9	**VERY LIGHT**
10	
11	**FAIRLY LIGHT**
12	
13	**SOMEWHAT HEAVY**
14	
15	**HARD**
16	
17	**VERY HARD**
18	
19	**VERY, VERY HARD**
20	

VITA

Rachel Duckham was born on the 9th September 1979 in Fareham, England. She spent most of her life growing up in a small village called St. Agnes, in Cornwall. She attended St. Agnes primary school from 1986 until 1990. In 1990 Rachel and her family moved to Hong Kong were she finished primary school and started secondary school. While in Hong Kong Rachel had the pleasure to begin her competitive love for track and field. She had the opportunity to represent Hong Kong in a number of track and cross-country events. In 1993, Rachel and her family returned to Cornwall, England where she attended Richard Lander secondary school and St. Austell College earning 9 GCSE, and 4 A-Levels. In 1999, Rachel was recruited to run track and field at McNeese State University. She gained her Bachelor of Science degree in Exercise Science in 2003 from Columbus State University, were she also finished her collegiate career in track and field. Before moving on to her Master degree, Rachel had the opportunity to work in the United States Olympic Training Center, Lake Placid, NY were she worked in the exercise sciences laboratory. She was responsible for carrying out various physiological tests as well as performance analysis on Winter Sports Athletes competing in Bobsled, Skeleton, Ice Hockey, Nordic Skiing and Biathlon. In 2004, Rachel entered the graduate program in Exercise Science, with a concentration in Exercise Physiology at the University of Tennessee, Knoxville. During her two years at the University of Tennessee, Rachel served as a Graduate teaching Assistant in the department of Physical Activities. In the summer of 2006 she received a Master of Science degree with a concentration in Exercise physiology.

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