# The Effects of Hiking Pole Use on Physiological Variables and Rate of Perceived Exertion While Hiking Uphill

By

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Abstract

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An increasing amount of hikers have added hiking poles to their outings to aid in reducing fatigue of the lower body and enhance stability. However, very little research has been conducted on the use of poles during continuous uphill hiking. The purpose of this study was to investigate the effect of pole use under field conditions on the rate of perceived exertion, physiological variables (oxygen consumption ($VO_2$), heart rate (HR), non-protein respiratory exchange ratio (RER), & total energy expenditure (TEE)), and time to completion during a 1.68 km continuous uphill (12.6% grade) hike. Ten male and ten female (Mean age = 22.7 ± 2.0 years) hikers participated in this experimental study using a within subject cross over design with randomized, counter-balanced order. Participants hiked with and without poles, at self-selected speeds. Rate of perceived exertion was collected at five minute intervals. Physiological measures ($V0_2$, HR, RER, and METs) were measured continuously (every two seconds) during all hiking conditions using a portable metabolic system (VmaxST, SensorMedics, Yorba Linda, CA). Heart rate data was recorded by a Polar transmitter belt worn by the participant with a receiver integrated into the VmaxST base system. Hiking pole use resulted in increased oxygen consumption

(M= 29.8 ± 2.6 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. M= 28.6 ± 2.8 $ml \cdot kg^{-1} \cdot min$), and total energy expenditure (M= 223.3 ± 57.9 kcals vs. 209.6 ± 47.7 kcals) compared to hiking without poles. Duration, RER, HR, and RPE were not significantly different between conditions. These results indicate that the use of hiking poles during uphill hiking increases the energy cost of hiking without increasing the perceived exertion in novice pole users. To fully evaluate the effects of hiking pole use and confirm the results from this study, future field research should be conducted with and without poles, including novice and expert groups, at grades above and below 15 %.

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# Chapter 1

## *Introduction*

The use of poles to aid in transportation can be traced back to between 3000-2000 B.C. when Scandinavians and other arctic dwellers, adapting to climatic conditions, used skis for hunting, gathering, and travelling during the winter months. Skis helped reduce the energy costs of transportation when food was sparse (Clifford, 1992). Travelers discovered that by using poles to propel themselves, it was possible to go faster and further; at this time one single, long pole was used to aid in transportation (Formenti, Ardigò, & Minetti, 2005).

It wasn't until the late 1800's that cross-country skiing transitioned from its functional roots into a sporting and recreational activity. The use of two poles was adopted by cross-country skiing competitors to aid in travel (Hoffman, 1992). After competitive cross-country skiing was introduced in the first winter Olympics in 1924, recreational cross-country skiing spread rapidly around the world (Formenti, Ardigò, & Minetti, 2005).

Cross-country skiers developed a type of off season pole walking to continue their training outside of the winter months. "Pole walking" has long been practiced in European countries, and in 1997 the trademarked Nordic walking poles were introduced. Nordic walking in its present form was established. "Pole walking", now known as, Nordic walking, combines the element of walking with the upper body conditioning of Nordic skiing (International Nordic Walking Federation or INWA, n.d.). Today, the practice of

Nordic walking is spreading in popularity among exercisers looking to burn more calories by turning their walking routines into full body workouts.

Hiking is one of the most popular forms of outdoor recreational activities. According to the Outdoor Industry Association's Annual Outdoor Recreation Participation Study for the United States (2009) and the American Hiking Society, between 32.5 to73 million Americans participate in some form of hiking and it remains in the top five most popular recreational outdoor activities. As opposed to Nordic walking, hiking is not an exercise used to maximize calories burned while walking; however, it is walking for recreation in the countryside and is continuous in nature, usually long in duration, and varies in intensity level. Prolonged uphill hiking can be strenuous and over longer periods of time may lead to early fatigue (Ainslie, Campbell, Frayn, Humphreys, Maclaren, & Reilly, 2002). Pole hiking has been promoted as a way to combat fatigue and enable longer more comfortable hikes, and an increasing amount of hikers have added poles to their outings (www.hikingequipmentsite.com/hiking-poles, 2010). As the popularity of pole use increases amongst hikers, the benefits of their use have come into question. Manufacturers of hiking poles claim that their use improves stability and ease stresses on the lower back and legs (Haid & Killer, 1995). Similar to Nordic walking, poles may be used to incorporate effective upper body power to improve overall walking performance by directing force from the pole plant back, thereby increasing the stride length and speed of the pole user (INWA, n.d.). It may be possible that incorporating these transportation aids into recreational activities, such as hiking, would enable individuals to reach a destination faster and more comfortably than without hiking poles.

However, very little research has been conducted on the use of poles during continuous uphill hiking. Existing research has predominantly been lab-based and has focused on identifying techniques for increasing energy expenditure with the use of hand weights or poles.  The increase in exercise intensity associated with treadmill walking with hand weights and pole use with the exaggerated "pumping" arm movement necessary to maintain greater speeds was found to result in increased heart rates (HR), oxygen consumption ($V0_{2)}$, and non protein respiratory exchange ratios (RER) when compared to walking without poles, with varying rate of perceived exertion (RPE) responses (Porcari, Hendrickson, Walter, Terry, & Walsko, 1997; Rodgers, Vanheest, & Schachter, 1995; Graves, Pollock, Montain, Jackson, & O'Keefe, 1987). However, as reviewed in Chapter 2, other studies have shown no significant differences in total energy expenditure (TEE) associated with pole use (Jacobson, Wright, & Dugan, 2000; Duckham, Basset, Fitzhugh, Swibas, & McMahan, 2009).

Pole use may also reduce RPE (Jacobson & Wright, 1998; Jacobson, Wright, & Dugan, 2000; Knight & Caldwell, 2000; Sklar, DeVoe, & Gotshall, 2003), improve speed (Willson, Torry, Decker, Kernozek, & Steadman, 2001), and reduce perceived fatigue (Duncan & Lyons, 2008), particularly when walking uphill. The energy cost of walking is proportional to the mechanical work done and includes supporting body weight and lifting and accelerating the center of mass (Grabowski, Farley, & Kram, 2005). The work performed on the center of mass during step to step transitions changes largely as a function of walking speed and step length, and is a major contributor to metabolic energy expenditure (Adamczyk & Kuo, 2009). For mechanical energy exchange to take place and reduce metabolic energy expenditure, an exchange of potential and kinetic energy needs to occur; as the slope of the incline increases, the body does not fall as far with each step as it is raised, as a result, there is less opportunity to recover potential energy and convert it into kinetic energy and additional work is required to move the body at the same velocity (Inman, 1967). At grades greater than 15% this energy exchange does not occur (Minetti, Ardigò, & Saibene, 1993) because little can be done to reduce the overall mechanical work when all work performed is done to lift the body mass during step to step transitions (Minetti, Moia, Roi, Susta & Ferretti, 2002). Maintaining speeds during uphill hiking conditions depends on the sustainable maximum metabolic power available, and the decreased metabolic cost that is associated with highly trained individuals (Minetti, Formenti, & Ardigò, 2006). It is possible that the use of hiking poles may aid in the mechanical work during hikes at greater inclines and may be responsible for the decreases in <u>perceived</u> exertion that are reported (Jacobson & Wright, 1998; Jacobson, Wright, & Dugan, 2000), but more research is needed in this area, as reviewed in Chapter 2.

According to the UIAA Medical Commission's consensus statement on the use of hiking sticks (Koukoutsi, 2008):

> in order to have any benefit from hiking poles, they must be used with the correct technique so that when pressed down upon, firm support is gained….Sticks need to be kept as close as possible to the body's line of fall, if the distance between the body and the hiking pole is too large, strain relief is greatly reduced and a strong turning movement can result.

The use of poles as intended, to reduce stress/load on the lower body and afford stability to the hiker, necessitates a more natural movement of the upper body in which the arm and leg swing occur at similar times relative to walking without poles (Koukoutsi, 2008). Contralateral limb movement, which is similar to the diagonal cross country skiing technique, may relieve knee extensor muscles, knee joint forces and during longer hikes, lessen fatigue of the lower limb muscles (Foissac, Berthollet, Seux, Belli, & Millet, 2008; Knight & Caldwell, 2000).

Pole use may also facilitate increased speed. Using poles as intended provides a greater propulsive force, which would result in a faster speed with the same physical effort. The distance traveled may increase if forward movement is aided by the loading of poles, which may allow the hiker to maintain greater speeds on ascent. This increase in hiking speed may decrease the time to reach a destination than hiking without poles.

Pole use may also reduce fatigue. The larger force applied to the poles during propulsion reduces stress on the lower limbs by transferring the load from the lower legs to the upper extremity (Knight & Caldwell, 2000; Foissac et al., 2008). This reduction of forces and recruitment of lower extremity musculature may prolong time to fatigue by lessening the sensation of localized fatigue (Foissac et al., 2008; Knight & Caldwell, 2000). However, novice pole users may fatigue more rapidly when using poles due to the increased upper body musculature involvement. Novice users may not gain all benefits of poles use and adaptations may occur as familiarity (McCormick, DeVoe, & Reiser, 2005) and upper body fitness parameters increase.

Pole use may also improve balance and stability. The INWA suggests that pole use may also be traced back to early times when shepherds and pilgrims used one or two sticks to make walking on uneven surfaces easier. Sticks have been used throughout history to aid backpacking travelers.

Load carriage during backpacking can increase the demands on muscles to support a greater weight during stance and to redirect and accelerate a greater mass during step to step transitions (Grabowski et al., 2005) resulting in an increase in the metabolic demand of the activity. The greater demand may be offset, however, by improved balance and stability associated with the use of poles. Balance and stability is enhanced with the use of one or two hiking poles, but during load carriage, the use of two poles has been shown to be more effective in aiding stability (Jacobson, Caldwell, & Kulling, 1997). Backpacking with poles has also been shown in some reports to be more comfortable for individuals and shown to make gait resemble that of load free walking with lengthening of stride and reduction in step frequency (Knight, &

Caldwell, 2000). Typically, as walking speeds increase, the biomechanical loads on the lower extremities also increase. However, Willson and colleagues (2001) found that the use of hiking poles increased stride length and velocity, but that the increase in velocity did not result in an increase in force production on the lower body. These results suggest a potential lessening of localized fatigue in the lower body while greater speeds are maintained.

Thus, overall, there is evidence that effectively using poles may reduce fatigue, increase speed, provide stability and increase the distance that can be comfortably traveled in a day by reducing stress on the lower body (Koukoutsi, 2008). However, much of the research examining these hypotheses and the effect of gradient has been conducted in a laboratory setting producing results that are difficult to generalize (Perrey & Fabre, 2008; Knight & Caldwell, 2000; Porcari, et al., 1997; Duncan & Lyons, 2008; Foissac et al., 2008; Jacobson, Wright, & Dugan, 2000). As reviewed in Chapter 2, only four field studies have been conducted (Sklar, DeVoe, & Gotshall, 2003; Saunders, Hip, Wenos, & Deaton, 2008; Jacobson & Wright, 1998; Duckham, Bassett, Fitzhugh, Swibas, & McMahan, 2009). These studies have found an increase in oxygen consumption associated with a decrease in RPE in all but one study. However, existing field studies have been limited by lack of adequate sample size, and/or length of trial. Moreover, existing field and laboratory settings have controlled participants' pace and intensity, which limits understanding of the effects of pole use on these variables.

Only 11 studies to date have examined the effect of pole use on RPE and found that without load carriage there were no significant differences in RPE between the pole and no pole condition. In the four studies conducted with load carriage, all but one showed significantly decreased RPE in the pole condition. Rate of perceived exertion is important, as it is correlated with physiological adaptations to exercise and used to gauge the level of intensity of an activity (Borg, 1982; Chen, Fan, & Moe, 2002). The lower the RPE, the longer the activity can be sustained.

*Statement of the Problem*

While hiking pole use is increasing in popularity (Heid, 2005) and widely promoted as a means to increase TEE and speed while reducing perceived exertion and fatigue, few empirical studies have actually examined the effects of hiking pole use on energy expenditure, speed, and RPE under field conditions among uphill hikers. Therefore, the purpose of this study was to investigate the effect of pole use on rate of perceived exertion, changes in physiological variables, and time to completion during a 1.68 km continuous uphill hike. Ten male and ten female hikers participated in this experimental study using a within subject cross over design with randomized, counter-balanced order.

*Hypothesis*

H□□: Mean oxygen consumption will be greater in the pole condition compared to the no pole condition during a 1.68 km uphill hike in a field setting.

$H_{\square 2}$: Mean heart rate will be greater in the pole condition compared to the no pole conditions during a 1.68 km uphill hike in a field setting.

*Exploratory Hypotheses*

$H_{\square 1}$: RER values will be greater in the pole condition compared to the no pole condition during a 1.68 uphill hike in a field setting.

$H_{\square 2}$: Ratings of perceived exertion will be lower in the pole condition compared to the no pole condition during a 1.68 km uphill hike in a field setting.

$H_{\square 3}$: Time to completion of a 1.68 km uphill hike in a field setting will be less in the pole condition compared to the no pole condition.

*Assumptions*

1. Subjects performed to the best of their ability.
2. Subjects followed pre-test requirements.
3. Subjects reported RPE accurately.
4. Measurements of $VO_{\square}$, HR and RER were reliable and valid.

*Limitations*

There are several limitations to this study. First, the field conditions in this study (e.g., grade, speed) were not as tightly controlled as in a laboratory setting; secondly, temperature, wildlife encounters, and recreational use of trail by mountain bikers, runners and other hikers could not be predicted and may act as potential confounding variable. Moreover, due to a malfunction in the Vmax, the first and second testing sessions for two participants were held over a six month period. Specifically, the first testing sessions began April through May 2009 and the second testing session was August-September, 2009. Two testing sessions took place, before and after the VmaxSt gas analyzer (SensorMedics, Yorba Linda, CA) was sent back to the manufacturer for maintenance.

The sample size in this study was small and consisted of self-selected college students, so findings may not generalize to the population at large; however, based on previous research (Porcari et al., 1997), our study was adequately powered (see POWER section). Also, subjects were recruited from Kinesiology classes and may represent a more physically active sample. As with any study, self-report measures and even objective measures are subject to bias and could limit the study's findings.

*Delimitations*

This study examined hikers in a field setting in an effort to better represent what a hiker would encounter in a natural setting. Although not a controlled lab setting, several procedures were in place to enhance study validity. These included gas analyzer calibrations before testing sessions and prior to each test, participants were trained in pole use method, attempts were made to keep testing temperature similar by testing in the morning or evening and re-testing at similar times, and collecting 24 hour diet and physical activity logs to ensure participants arrived for each trial in similar nutritional and physical states. Field conditions were also carefully measured. Testing took place on a trail at Cerro San Luis Obispo Mountain. The hiking pole practice trial and warm up began at an elevation of 63.09 meters and ended at 103.02 meters over a distance of .41 km at an average grade of 9%. The total length of the testing trail was 1.68km, measured with a measuring wheel (Stackhouse Athletic Equipment, model CTMMW, Salem, OR), starting at 63.09 meters in elevation and ending at an elevation of 300 meters. The average grade of the mountain trail was 12.6% (Garmin Fitness GPS, MotionBased v 2.3, San Francisco, CA). The first and second testing sessions were separated by at least 48 hours.

The sample size of this study was small (N = 20), but the study was nonetheless adequately powered based on previous research (See Power section below). The sample was selected to identify a healthy college aged population with little previous pole use experience. Specifically, this study tested 20 college aged (10 males and 10 females) volunteers. To be enrolled in the study, participants had to self-report being moderately active (at least 3 days per week), and not involved in training for sports competition. This was done to identify a population who were active, healthy, and representative of the general population. Participants also had to self-report being novice pole users. This was done to eliminate any effects of varying pole use experience. For participant safety, they also had to report no history of cardiovascular disease.

*Significance of the Study*

This study was the first to test the effect of pole use on energy expenditure and ratings of perceived exertion in a gender balanced cross-over study design under field conditions. Findings from this study will help inform whether pole use in hikers helps improve speed, RPE ratings, and reduce the energy costs of hiking uphill. Findings from this study have the potential to impact the field of pole hiking, practiced by an estimated 3.2 to 7.3 million Americans (Outdoorindustry.org, 2009; Americanhiking.org, n.d.; Heid, 2005), by determining the degree of energy expenditure associated with the use of hiking poles and aid the decision of those seeking to use poles to ease the physical demands of hiking.

*Definition of Terms*

Hiking poles (also known as trekking poles, hiking sticks or walking poles) are used while hiking. They are made from light weight aluminum or carbon fiber and are adjustable height wise and resemble ski poles.

Rate of Perceived Exertion (RPE) is a subjective rating of how hard an individual is working (intensity level) at any given time based on the Borg 6-20 scale (Borg, 1998).

Non Protein Respiratory Exchange Ratio (RER) is the ratio between $CO_2$ produced and $O_2$ used (.7-1.2). Is used as an indicator of which fuel (carbohydrates, mixed, fat) is being metabolized for energy.

Relative oxygen consumption ($VO_2$) is the volume of oxygen in milliliters utilized by the body in one minute per kilogram of body weight.

# Chapter Two

## *Review of the Literature*

In this chapter, literature related to hiking pole use, energy cost, oxygen consumption, HR and RPE are examined. The focus of this chapter is to describe the research that has been conducted to date in order to evaluate the effects of hiking pole use during uphill hiking under field conditions. Since there is lack of scholarly work on this topic, literature related to pole use, oxygen consumption, and energy expenditure from laboratory and field experiments were included in order to give a background on prevailing notions of hiking pole use.

As noted earlier, hiking poles are commonly used and thought to assist in reducing perceived exertion and actual energy expenditure. However, the following review will illustrate, that this remains unclear.

There are several factors to consider when evaluating the quality of studies of hiking pole use. During any bout of physical activity, there will be a variation in physiological response based on a number of factors. For the hiker this depends on factors such as: the intensity level of the hike (pace), the duration of the hike, the physical fitness level of the hiker, dietary intake, backpack weight, weather conditions and severity of terrain (Ainslie, Campbell, Frayn, Humphreys, Maclaren, & Reilly, 2002). As reviewed below, researchers have accounted for these variables with varying frequency.

*Laboratory studies*

The effect of hiking poles on energy expenditure and RPE remains unclear in current laboratory-based literature. Several laboratory studies have been conducted (Perrey & Fabre, 2008; Knight & Caldwell, 2000; Porcari, et al., 1997; Rodgers et al., 1995; Duncan & Lyons, 2008; Foissac et al., 2008; Jacobson, Wright, & Dugan, 2000), but results have been obtained from varying grades, walking speeds and protocols making it difficult to draw conclusions.

Perrey and Fabre (2008) examined the effects of pole use when walking either uphill, on level ground, or downhill, on RPE and physiological variables (HR, RER and $VO_2$). Twelve recreational Nordic walkers were tested, including five men and seven women between the ages of 22 and 49 in a laboratory setting.

Subjects walked on a treadmill at a preferred walking speed for 10 minutes in each condition with the last five minutes dedicated to data collection (0% and ± 15% grade, ± 15% additional body mass and with and without poles) on two separate occasions. Findings indicated no hiking pole effects on preferred speed, and lower stride rate values while hiking uphill with poles than without poles. This failure to elicit kinematic changes in stride length thought to be associated with the use of hiking poles may be due to the lack of pole plant time experienced on a motorized treadmill. This may ultimately decrease the propulsive impulse and limit recruitment of the upper body musculature to aid in propulsion. Limited recruitment of upper body musculature may also explain why when walking on level ground or uphill on a treadmill at a preferred pace, the addition of hiking poles did not significantly alter the physiological response or perceived exertion of the hiker. The authors concluded that when hiking poles are used without excessive movement, no additional energy expenditure occurs in the level or uphill pole condition. However, as with this and the following laboratory studies, the use of hiking poles on a motorized treadmill may not provide the walker with the same effects, if any, as when in a natural setting.

Foissac et al. (2008) similarly investigated the physiological effects, as well as, examined the electromyographic (EMG)activity of using hiking poles during uphill walking at a preferred pace. Eleven male volunteers between the ages of 20 and 30 participated. The subjects walked at 3 km/hr on a treadmill inclined at 20% grade. The researchers determined preferred walking frequency by counting the number of steps over almost a minute. A metronome was used to keep step frequency consistent. Before each trial, the speed was adjusted to the preferred pace, +20% or -20% of the preferred pace and maintained for four minutes in each condition. Of the 12 conditions tested, the conditions of interest to this study were: 1) the subjects carrying the poles, but not using them; 2) subjects using poles (three pole weights were tested); and, 3) not using poles. There was no significant difference in $VO_2$ among the carrying of poles, the no pole condition and the pole conditions. Although carrying or using poles up to 360 g required more muscular activity of the upper limbs, this did not result in an increased energy cost. Walking with poles at high frequency, however, significantly increased energy cost compared to preferred frequency and low frequency pole conditions. Electromyograhic recordings for upper body muscular activation were significantly higher for the low frequency condition compared to the preferred frequency ($p = 0.045$) and high frequency conditions ($p = 0.018$). There was a general trend towards a reduced upper body EMG recording (triceps brachii and anterior deltoid) during the push phase of the cycle and lower EMG recording of the anterior deltoid during the recovery phase of the cycle for the high frequency pole condition. Significant differences ($p = 0.025$) were found for the gluteus maximus between high and low frequency conditions with higher EMG recordings during the push phase for the high frequency condition. When subjects walked with poles at preferred frequency conditions, there was a significant (15 %) decrease in activation of the lower body as the upper limbs exhibited a 95% increase in activation. These results indicate that the reduced loading of the lower extremities found with pole use may lessen localized fatigue by transferring more load to the upper body at low speeds and that preferred pace may be optimal for minimizing overall energy cost per distance traveled. However, it appears that mean $VO_2$ for low frequency walking was slightly greater than that of preferred frequency, although not statistically significant. This may suggest that at lower speeds an increase in energy cost may be associated with the increased upper body muscle recruitment while planting and pushing off of the pole before and during propulsion. These results suggest that any increase in energy cost at greater speeds may be associated with the exaggerated arm movement, not the planting of or weight of the pole, needed to maintain a faster walking frequency or the imposed walking frequency, as there were no significant differences between the pole and no pole conditions on $VO_2$. As this study only included men, it is unclear whether these findings would generalize to women.

Porcari et al. (1997) measured $VO_2$, caloric expenditure and RER on sixteen men and sixteen women between the ages of 19 and 33. The researchers hypothesized that the use of poles would significantly increase the physiological responses to self-paced walking and that the increases would be similar for men and women. Two twenty-minute walking trials on a level treadmill with self-selected walking pace were studied. The men walked at an average of 4.3 mph ± .25 mph and the women walked at an average of 3.8 mph ± .41 mph.

Walking with poles significantly affected the physiological responses to exercise. Average HR, $VO_2$, energy expenditure (kcal/min), and RER were all significantly higher in the pole condition ($p<.05$). Rate of perceived exertion (RPE) was also recorded and was significantly higher in the pole condition ($p<.05$). Although, men consumed significantly more oxygen, and burned more calories than women, the magnitude of the change between conditions was similar for both sexes.

Similar to Porcari et al. (1997), Rodgers et al. (1995) examined pole use as a modification of walking (Exerstriding) to increase intensity and subsequent caloric expenditure. Ten female subjects (23 ± 4 yrs) completed two trials of treadmill walking at 6.7 km/hr at 0% grade for 30 minutes. Pole use significantly increased average $VO_2$ ($p\leq.05$), average RER ($p\leq.05$), average HR ($p\leq.05$) and TEE ($p\leq.05$), while RPE was not significantly ($p>.05$) different between conditions. The speeds used by Porcari et al. (1997) and Rodgers and colleagues (1995) were considerably greater than the two previous studies (Perrey and Fabre = 4.1 ± .6 km/hr; Foissac et al., = 3 km/hr). Both Perrey and Fabre (2008) and Foissac and colleagues(2008 ) had no significant changes in physiological variables between pole conditions; however, Porcari et al. (1997) did find that the greatest differences in energy cost between conditions occurred at the slowest walking speeds with differences between conditions reduced at greater speeds. These results may be explained by the longer cycle rates at slower speeds; more upper body musculature is recruited for the propulsive phase and as speeds increase, cycle rates are reduced and the propulsive phase time is decreased. It may also be that as testing duration increases, the effects of pole use may be revealed. This study was also conducted on a level treadmill, and confirms that the increased swinging action of the upper arms and body, which have been shown alone to increase oxygen consumption and even to a greater degree when weight is added (Maud, Stokes, & Stokes, 1990), may explain the increase in energy cost more effectively than the use of poles alone, especially when walking at a level grade on a treadmill at greater speeds.

Laboratory studies have also examined pole use in backpacking conditions, when the load carried is substantial. The use of hiking poles in such a setting may prevent some of the kinematic alterations associated with carrying a heavy load (shortened stride length) and produce gait that resembles similar characteristics of unloaded walking (i.e. lengthening of stride and reduction in step frequency) (Knight & Caldwell, 2000). Increased step frequency has been associated with an increase in oxygen consumption (Foissac et al., 2008; Adamczyk & Kuo, 2009; Zarrugh & Radcliffe, 1978).

Knight and Caldwell (2000) investigated the use of hiking poles and their potential to reduce the stresses imposed by a heavy backpack load. Interestingly, the researchers hypothesized that the oxygen cost of backpacking with hiking poles would not differ from that of backpacking without poles, despite the use of additional upper body musculature. Ten volunteers were recruited, five male and five female (30 ± 12 yrs) regular backpackers. The subjects walked on a treadmill inclined at 5˚ while carrying a load of 30% of their body mass for one hour. Kinematic and EMG data was collected. The speed was determined prior to testing to control intensity and was set so that the subject's heart rate was between 55 and 65% of their age-predicted heart rate maximum in the no pole condition and on average was 3.7 ± 0.8 km/hr. No significant difference in speed was observed during the pole and no pole conditions; however, there was a 6.7% increase in stride length and 6.3% decrease in stride frequency in the pole condition. These kinematic changes were associated with a reduction of EMG activity of the lower extremities with an increase in activity for the upper body. There was no significant increase in $VO_2$ during backpacking with poles compared to backpacking without poles while carrying a load (22.4 ± 3.1 kg) on a treadmill inclined at 5%. However, RPE was significantly ($p \leq .003$) lower in the pole condition than in the no pole condition despite a significant increase in mean heart rate ($p \leq .01$).

This study used a backpacking load that was substantially heavier than one would carry on a day hike and found that the use of poles in this condition did not increase the metabolic cost, but reduced the perceived exertion at the same intensity level. The decrease in RPE may be associated with the stability afforded to the hiker with the use of poles when his or her center of mass was raised and/or the redistribution of muscular demand which may have decreased the sensation of lower extremity fatigue. The authors believed that the higher heart rates observed in the pole condition resulted due to the addition of upper body musculature and not an increase in the workload. Moreover, they hypothesized that this increase in metabolic cost of the upper body musculature was offset by a reduced metabolic cost in the lower extremities. These physiological results are in line with previous studies of similar speed (Foissac et al., 2008; Perrey & Fabre, 2008).

Similar to findings by Knight and Caldwell (2000), Jacobson, Wright and Dugan (2000) examined physiological variables (HR & $VO_2$), caloric consumption (Kcals/min) and RPE on load carriage during moderate grade treadmill walking with and without the use of hiking poles. The subjects were 20 Caucasian men ages 20-48 with little previous load carriage experience. Subjects walked on a treadmill at 1.5 mph for 15 minutes with a load of 15 kg; a natural and comfortable arm swing was encouraged. The testing protocol was: 1 minute at 10% grade, 2 minutes at 15% grade, 2 min at 20% grade and 10 minutes at 25% grade. The researchers found that mean $VO_2$, energy expenditure and HR were not significantly different between the two conditions. Rate of perceived exertion was significantly ($p < 0.05$) lower. These results support the notion that no additional energy is expended during inclined walking on a treadmill with load carriage while using hiking poles at a slow or preferred pace; however, there is a significantly greater decrease in perceived exertion.

Duncan and Lyons (2008) used a similar protocol as Knight and Caldwell (2000), but with six men and one woman (mean age 24.2 ± 4.7) with hill walking experience and without load carriage. The authors examined the impact of one hour simulated uphill walking with and without hiking poles on oxygen uptake and perceived exertion. In conflict with the results of Knight and Caldwell (2000) and Jacobson et al., (2000) $VO_2$ was found to be significantly higher in the poles condition ($p = .001$) than the no poles condition. However, similar to the other studies, there was a trend for RPE to be lower in the poles condition compared to the no pole condition.

Overall, findings are mixed on the effects of pole use on $V0_2$. The reason behind the difference in findings with regard to $V0_2$ is unclear but may be due to differences in incline, duration, speed, load carriage, sample size and sample characteristics. Significant increases in oxygen consumption may have less to do with the mass, or use of poles, but more to do with the exaggerated arm movement necessary to maintain greater speeds on a treadmill and imposed step frequencies. Surprisingly, few studies have been conducted in the field using hiking poles as intended to support or refute these results (Sklar, DeVoe, & Gotshall, 2003; Saunders, Hip, Wenos, & Deaton, 2008; Jacobson & Wright, 1998; Duckham, Bassett, Fitzhugh, Swibas, & McMahan, 2009).

*Field studies*

In one of the few field studies, Sklar, DeVoe and Gotshall (2003) examined the metabolic responses while hiking with and without trekking poles (hiking poles) at self-selected pace and intensity during a trail hike. Six women and seven men between the ages of 19 and 27 volunteered to participate. Each participant performed two hikes of 4km in length consisting of a 2km (9% grade) ascent to the summit (1860 m from 1510 m) and back on the same day. Each hike was performed at a self-selected pace and intensity to ensure completion. Throughout testing the temperature ranged from -7˚C to 16˚C. The average hiking speed was 8.3 ± 0.9 to 8.6 ± 0.5 km.hr$^{-1}$ in the uphill portion of the hike with no pre-set time to completion between trials. Oxygen consumption was significantly higher ascending ($p < 0.001$) while hiking in the pole condition. Rate of perceived exertion was significantly lower in the pole condition ($p < 0.001$) compared to the non-pole condition. Mean energy expenditure was significantly higher in the ascending condition with poles ($p < 0.001$) compared to the ascending condition without poles. Total energy expenditure was also significantly higher ($p < 0.001$) in the uphill condition with poles as compared to the ascending condition without poles. The average HR in the ascending pole and non pole conditions were not significantly different.

This study suggests that the use of hiking poles in a natural setting increases oxygen consumption and energy expenditure while decreasing the RPE during ascending portions of a trail hike. The increased energy cost may be associated with the increased muscle recruitment of the upper body, which may have helped decrease some of the force exerted on the lower extremities. These results are similar to the results of Foissac et al.'s (2008) high frequency walkers who displayed the highest rates of oxygen consumption. Rate of perceived exertion data was only collected one time after ascent and one time after descent in both trials; thus, it is possible that the average response would be altered if examined over time.

Similar to Sklar, DeVoe and Gotshall (2003), Saunders, Hipp, Wenos and Deaton (2008) found an increase in energy expenditure; however, in contrast to Sklar and colleagues' findings, the researchers found a significantly higher mean heart rate, and no significant differences in RPE in the pole or no pole condition. Fourteen fit male (mean age, 22.1 ± 2.1 years) recreational hikers participated in this study which was conducted to determine if trekking poles altered physiological and RPE responses to hiking on varied terrain, and whether the responses were dependent on grade. The subjects chose a walking pace in their first trial and a metronome and time splits for each trail segment were used to control for speed of hiking between pole trials. The hiking course consisted of approximately 200 m segments of terrain at level, 5% uphill, 10% uphill, 10% downhill and 5% downhill and was approximately 1.25 km in length. Oxygen consumption (independent of grade) was significantly higher in the pole condition ($p < 0.05$) compared to the no pole condition. Heart rate was also significantly ($p < 0.05$) higher in the pole condition. Rate of perceived exertion was not significantly different between pole conditions. No significant pole x grade interaction was observed between conditions, indicating that the effect of hiking poles may be independent of the grade of the trail examined. In this study, the use of hiking poles increased the physiological demand for fit, recreational hikers at self-selected, but maintained speeds, at varying terrain without increasing perceived effort. The hiking intensities were low to moderate and the distance hiked in each segment was very short (150 to 200 m). As this study evaluated hiking over fairly short segments, a longer trial may be necessary to fully evaluate effects of pole use in field conditions. Also, this study only included men; it is unclear whether these findings would generalize to women.

Jacobson and Wright (1998) recruited 11 (three women and eight men) novice pole users, aged 18 to 21 to participate in a field study to compare HR and RPE during steep grade ascents and descents with and without poles while wearing a 15 kg backpack. Testing was done on a 50 m, 40˚ slope with two continuous trials and a 15-second data collection stop in-between. To maintain hiking pace, a metronome was set at 72 steps per minute. A significant difference for HR was found only during the first ascent ($p < 0.05$); the second ascent was not significantly different. The researchers believed that the initial difference in heart rate may have resulted from the small sample size and individual differences or it may be that initial heart rate response is lower with poles. Rating of perceived exertion was significantly lower on all trials when hiking poles were used ($p < 0.05$) and may be due to the stability gained with the use of poles at this grade and the distribution of work to the upper body. The length of the trials and grade used make this study difficult to compare. Longer trials may be necessary to fully evaluate any differences.

Duckham, Bassett, Fitzhugh, Swibas, and McMahan (2009) examined the effects of hiking poles on performance, physiological variables and RPE during a maximal effort mountain ascent. Fifteen physically active (regular hikers) men and women (mean age 29 ± 6 years) hiked a 4.42 km trail with 426 m of elevation gain with and without poles in counter-balanced order with one week between tests. The participants were instructed to hike at maximal effort, but not to run. Performance was determined by the time taken to walk the trail and the blood lactate accumulation. There were no significant differences ($p = .570$) in time to completion or ($p = .347$) blood lactate between conditions. No significant difference in physiological responses (mean HR $p = .673$ and estimated energy expenditure $p = .638$) or RPE were observed. These results indicate that using hiking poles may not affect performance during a maximal effort mountain ascent, as measured by time to completion, or alter energy expenditure and perceived exertion; however, with maximal effort, the differences in energy cost between conditions may be reduced. This is in line with Porcari and colleagues (1997) who discovered that the greatest differences in energy cost occurred at the slowest speeds with differences reduced at greater speeds. It is unlikely that hikers on longer duration outings would maintain maximal effort; therefore, additional research is necessary to determine if these results would be similar at self-selected, sub-maximal speeds.

Overall, results from the few available field studies suggest that when hikes are short in duration (50-250 m) there is an increased cardiovascular and metabolic response to uphill hiking with hiking poles without a perceived increase in difficulty (Jacobson & Wright, 1998; Saunders et al., 2008; Sklar et al., 2003), but there are exceptions in the literature (Duckham et al., 2009). More research is clearly needed to determine the effects of hiking pole use during continuous uphill hiking under field conditions. Field studies are not as tightly controlled as laboratory studies, but may have a more direct application to hikers, backpackers and mountaineers. More uniform testing and realistic conditions should facilitate future researchers to discover the effects of hiking pole use during continuous uphill hiking.

# CHAPTER 3

## *Methods and Procedures*

The purpose of this study was to investigate the effects of hiking pole use during continuous uphill hiking on physiological variables and rate of perceived exertion. This experimental study utilized a within subject, cross-over design in which the participants completed both hiking conditions in a randomized, counter-balanced order. This chapter describes the participants, instrumentation, independent and dependent variables, testing procedures and the statistical analyses used in this study.

*Power and Sample Size*

Sample size determinations were based upon a laboratory-based study by Porcari et al. (1997) in 16 men and 16 women. Based on these data, expected changes in the pole vs. no poles condition on $VO_2$ are 24.0 ml·kg$^{-1}$·min$^{-1}$ vs. 19.6 ml·kg$^{-1}$·min$^{-1}$, respectively and a standard deviation of 3.2, yielding an effect size of 0.57. For RPE, expected changes in the pole vs. no pole condition, respectively, were 11.9 vs. 10.4 with standard deviation of 1.8, yielding an effect size of .38. For HR, expected changes in poles vs. no poles, respectively, were 132.0 bpm vs. 114.0 bpm with standard deviation of 15.0, yielding an effect size of .51. With 20 subjects, assuming a type-I error rate of 0.05, the power was >.80, .73, and >.80 for testing the null hypothesis of no effect for poles on $VO_2$, RPE, and HR, respectively.

*Participants*

Volunteers were recruited from Kinesiology classes at California Polytechnic State University, San Luis Obispo. To be enrolled in this study, participants had to report moderate physical activity at least three times per week for thirty minutes per day, no involvement in training for competitive sports, and no previous pole use experience. These selection criteria were designed to identify healthy individuals, representative of the general population, with no expert hiking or pole use experience. Prior to participation, a Physical Activity

Readiness Questionnaire (PAR Q, ACSM, 1997), and AHA/ACSM Health/Fitness Facility Pre-participation Screening questionnaire (ACSM, 1998) were used to select low risk participants. Potential participants were screened for readiness and willingness to participate, and medical contraindications to exercise such as symptoms suggesting cardiac or pulmonary disease, dyspnea at rest or during light exercise, angina, dizziness or lightheadedness and risk factors for coronary artery disease, including family history, cigarette smoking, hypertension, dyslipidemia, impaired fasting glucose, obesity, and sedentary lifestyle, and orthopedic complications. Conditions that may prevent adequate effort, risk to the participant (e.g. asthma or severe allergies), or compromise the validity of the research results were also screened.

Of the 32 potential participants recruited for the study, 12 were unable to participate for the following reasons: one was ineligible due to orthopedic constraint, two were ineligible due to risk factors and failure to meet inclusion criteria and nine were unable to schedule two hiking trials. Twenty novices, moderately fit participants (10 men, 10 women) were deemed eligible and enrolled into this study. The descriptive statistics of the participants are presented in Table 1. The participants ranged in age from 19 to 26 years, heights ranged from 154.9 cm to 188.0 cm, and weight from 54.5 kg to 125.0 kg. The human subject's proposal was approved by the California Polytechnic State University, San Luis Obispo Human Subjects Committee.

*Procedures and Instrumentation*

After initial screening, eligible participants reviewed and signed informed consent forms and were made aware of all possible benefits (e.g., increased physical activity, enjoyment of hiking) and risks of their participation (e.g., possible discomfort during exercise, muscle soreness and fatigue) and the right to withdrawal from the study at any time.

In an effort to standardize assessment conditions and limit variables that could potentially affect performance, participants were asked to refrain from alcohol, caffeine, tobacco and strenuous physical activity for 24 hours prior to testing as well as refrain from eating for three hours before data collection began (Saunders et al., 2008). Subjects were asked to record their dietary intake and physical activity for 24 hours before the test and to replicate these habits and resubmit their food intake and physical activity records at the next trial. This information was collected to ensure that participants presented for each experimental trial in the same nutritional and physical state. Data collection ran for two, 4-week sessions with 26 tests completed from April-May, 2009 and 14 tests completed from August-September, 2009. Whether or not the participants began with the pole or no pole condition first was assigned randomly by pulling a slip marked P or NP from a container prior to arriving at the testing location. Participants were scheduled based on their availability; however, to minimize the effects of diurnal variation, every effort was made to conduct tests at the same time of day. In the second round of testing (August-September), tests took place in the early morning (start by 7-10 a.m.) or evening (after 5p.m.) to avoid high temperatures and time of day for re-test was kept similar. Time of day was recorded to examine effects of morning or evening testing in both testing periods. The re-test session was no sooner than 48 hours after the first trial or longer than two weeks apart, except for two cases in which the re-test session occurred three months apart.

At check-in, 24 hour food and physical activity logs were reviewed to confirm adherence to pre-testing guidelines. Participants completed a brief questionnaire (see Dependent measures) and were then re-instructed on testing procedures (i.e., reporting RPE, self-selected pace without running). In each condition (pole and no pole), the participant was instructed to hike continuously for the pre-defined hike distance at a self–selected pace without running. A self-selected pace was chosen based on previous research methodology under field conditions (Sklar et al., 2003; Duckham et al., 2009) and research on enforcing stride frequency (Foissac et al., 2008; Grobowski et al., 2005; Zarrugh & Radcliffe, 1978).

Research on enforcing stride frequency suggests that there may be a self-selected optimal pace that is efficient while walking. It may be that there is an optimal pace while using hiking poles. Research by Grobowski et al., (2005), suggests that enforcing stride frequency may potentially increase the cost of movement. Freely chosen step rates require the least oxygen consumption at any given speed and other forced step rates at the same speed increase the oxygen cost over that required for the self-selected step rate (Zarrugh & Radcliffe, 1978; Foissac, et al., 2008).

Prior to testing, participants were provided instructions regarding how to properly use hiking poles (12 oz/pole). Instructions for hiking pole use were in handout form and included these instructions:

> The rhythm for pole movement becomes natural if you move them with the natural swing movement of your arms, as in normal walking. One leg swings forward as the opposite arm does…consider hiking poles as an extension of your arms, as you swing your arm forward, plant the pole with tip angled back…As you step, push down on the poles to help you move forward; keep your elbows in, close to your body (http://www.ideal-hiking-equipment.com).

The hiking poles were equipped with adjustable, telescopic sections and wrist straps, and were individually fitted for each participant according to the manufacturer's recommendations. The hiking poles were adjusted for the pole condition so that the elbow of the participant was at 90 degrees while the pole was held vertically and in contact with the ground.

Participants were then fitted with the portable metabolic system (VmaxST, Yorba Linda, CA). The VmaxST Base System was secured to the participant using a shoulder mount harness with plastic sliders. A mesh head cap with Velcro adjustments was used to hold the Hans-Rudolph mask securely over the nose and mouth. The Hans-Rudolph mask was used to collect expired gas and was attached to the Triple V Volume Transducer. The sample line was plugged into the gas outlet on top of the volume transducer and connected to the VmaxST base system (SensorMedics, Yorba Linda, CA). Prior to pilot testing and each testing series the VmaxST was calibrated for expiratory air volume, $O_2$, and $CO_2$ measurements according to the manufacturer's guidelines. The measured volumes of expiratory and inspiratory values did not differ by more than three percent from that of the calibration syringe volume (3L). Ambient air samples of $O_2$ and $CO_2$ was compared with a reference gas (15 % $O_2$, 5% $CO_2$, bal. in $N_2$). Before each test, and after an initial 30 minute warm up, a one-point calibration measurement (ambient air measurement) was performed. This was to ensure accuracy of the gas calibration. After reading pole use instructions and being fitted with the VmaxST and hiking poles, participants warmed up and practiced hiking with poles over a .41 km distance.

During data collection, the researcher walked behind the participant so as not to alter the self-selected pace of the participant while collecting RPE data every five minutes. Participants used their fingers to signal RPE's to the researcher without speaking, turning their heads, bodies or stopping. An 8.5" by 11" sign was used to display Borg's rate of perceived exertion scale prior to testing to aid subjects in identifying their exertion levels, but was not needed during testing. A stop watch was used at the start of each trial, to time each five minute RPE collection, and to collect time to completion data. Following each testing day, the data collected was downloaded to a computer with MetaSoft support software (SensorMedics, Yorba Linda, CA).

*Test location*

A hiking trail on Cerro San Luis Obispo, also known as, Mt. Madonna was chosen because of the proximity to California Polytechnic State University. Moreover, the testing location was free of debris that would make hiking pole use difficult. Subjects met the researcher at the trailhead of Cerro San Luis Obispo at the intersection of Marsh St. and Hwy 101 at their scheduled times.

The hiking pole practice trial and warm up was .41 km at an average grade of 9.2%, beginning at an elevation of approximately 63.09 m and ending at approximately 103.02 m of elevation. The total length of the test trail was 1.68km. Both the warm up and the testing trail were measured with a measuring wheel (Stackhouse Athletic Equipment, model CTMMW, Salem, OR). The test trail started at approximately 103.02 m and ending at approximately 300 m, the average grade of the mountain trail was 12.6% (Garmin Fitness GPS, MotionBased v 2.3, San Francisco, CA).

*Data Collection*

*Pilot testing*

Pilot testing was conducted with two students (one male and one female) in the laboratory and in the field prior to actual data collection. Pilot testing verified that the researcher could correctly administer the tests and treatments with appropriate participants.

*Independent Variables*

This study examined the effects of pole use while controlling for sequence (i.e., whether poles or no poles was done first) and pre-testing conditions.

*Dependent Variables*

Physiological measures (HR, RER, $VO_2$ and METs) were measured continuously during all hiking conditions using a portable gas analysis system (VmaxST, SensorMedics, Yorba Linda, CA). Heart rate data was recorded by a Polar transmitter belt worn by the participant with a receiver integrated into the VmaxST base system. Data for each dependent measure (i.e., $Vo_2$, HR, RER and METs) was recorded with the VmaxST portable metabolic system which records every two seconds and was downloaded to a computer for metabolic calculations using metabolic stress test software (Metasoft, Version 1.11). The data was then downloaded into excel and exported into SPSS statistical software version 9.0 (SPSS, Inc., Chicago, IL). Relative oxygen consumption was measured to the nearest 0.1 ml·kg$^{-1}$·min$^{-1}$ throughout each trial. RER was determined using MetaSoft software. Average energy expenditure was determined by averaging METs over the duration of the trial and using ACSM's energy expenditure formula:  average METs was multiplied by 3.5 and the participant's weight (kg) and divided by 200 (ACSM, 2005). The `gold standard' method of measuring energy expenditure is the doubly labeled water method, which is also a form of indirect calorimetry, as it measures $CO_2$ production; however, the availability, number of participants, price and analysis involved made it impractical for use (Ainslie, Reilly, & Westerterp, 2003). The indirect calorimetry method used in this study to measure respiratory gas exchange both in the laboratory and in the field has been validated against the doubly labeled water method and provides an accurate method of measurement (Ainslie, Reilly, & Westerterp, 2003; Schoeler & van Santen, 1982). The reliability and validity of current portable gas analysis systems including the VmaxST have not been established in field conditions (Macfarlane, 2001); however,in laboratory conditions the VmaxST has demonstrated excellent reliability and validity for measuring $VO_2$ and HR across a range of exercise intensities (Perkins, Pivarnik, & Green, 2004).

Measurements of RPE were obtained every five minutes during each trial by the researcher to examine changes over time. Average RPE was computed by averaging all reported RPE at each five minute collection point. The researcher recorded time to completion for each trial. Rate of perceived exertion has been studied in laboratory and field studies in both healthy and diseased populations and has been shown to be a valid indicator of the degree of physical strain experienced during dynamic exercise (Borg, 1982). Rate of perceived exertion is associated with the physiological adaptations to exercise and is a valid measure of exercise intensity (Chen, Fan, & Moe, 2002).

Information was also collected on demographic variables (age, sex, etc.), weight, and height. These were measured prior to the hike; weight in light clothing without shoes was recorded using a MED-WEIGH MS-3200 digital sale (Brooklyn, NY) and recorded to the nearest 0.1kg. The scale was calibrated with a 20 kg weight. Height was recorded using a statiometer (Ellard Instrumentation, Monroe, WA) and measured to the nearest 0.1 cm. The statiometer was calibrated using a meter stick and both were matched for height.

Participants also reported enjoyment of physical activity and hiking and pre-hike energy and pre-hike fatigue level by filling out a brief questionnaire prior to the hike. The questionnaire queried on the number of hours slept the previous night, followed by four likert scale questions: 1) How tired do you feel right now? On a scale from 1-7, 1=not at all and 7=extremely tired, 2) How much energy do you have right now? On a scale from 1-7, 1=none and 7=endless amounts, 3) How much do you enjoy physical activity? 1=not at all and 7=very much, and 4) How much do you enjoy hiking? 1=not at all and 7=very much. This questionnaire was created and used by the researcher to assess the rest and energy levels of the participants prior to hiking and to ensure that subjects presented for each experimental trial in the same physical state.

*Statistical analyses*

Continuous data for each dependent measure ($VO_2$, HR, TEE, RER, and RPE) was averaged across the trial for each pole condition. Descriptive statistics are presented in the results tables as either means $\pm$ SDs for continuous measures or percentages for categorical responses. Repeated measures analysis of variance (ANCOVA) were conducted with each dependent measure ($VO_2$, HR, TEE, RER, and duration) as a within-subjects factor, and condition (pole, no pole) as a between-subject factor. Gender, starting condition, time of day, hiking experience, weight of hiker, enjoyment of hiking and physical activity were also entered as covariates given their potential influence on performance. Rate of perceived exertion was also analyzed using the nonparametric Wilcoxon matched pair test. Statistical analyses were performed with SPSS statistical software version 9.0 (SPSS, Inc., Chicago, IL). Alpha was set at 0.05 for statistical significance.

CHAPTER FOUR

*Results*

The physical characteristics of the participants are summarized in Table 1. On average, participants were 22.7 ± 2.0 years of age, 172.2 ± 11.5 cm tall and weighed 73.5 ± 17.5 kg. Significant differences ($p > 0.05$) in physical characteristics by gender appeared only in height and weight. As shown in Table 2, there were no significant differences in the average hours of sleep the night before each trial or in pre-hike vigor and fatigue between conditions. One recording was not downloaded from the portable metabolic system (VmaxST, SensorMedics, Yorba Linda, CA) due to technical difficulties; therefore, physiological data are presented for 19 or 20 subjects accordingly. No interactions were found between the following dependent variables and gender.

*Duration and Speed*

As shown in Table 3, there were no significant differences ($p = .48$) in time to complete the 1.68 km when hiking with or without hiking poles ($M = 20.2 \pm 1.3$ min vs. $M = 20.0 \pm 1.4$ min, respectively) at a self-selected pace ($F(1, 19) = .531$, $p = .48$) with and without adjusting for covariates including gender, weight, hiking experience, time of testing (a.m. or p.m.), and starting condition (pole vs. no pole). There were also no significant differences in average hiking speed, which were 5.15 ± .31 km/hr (range of 4.5 to 5.5 km/hr) in the pole condition and 5.15 ± .37 km/hr (range of 4.7 to 6.0 km/hr) in the no pole condition.

*Oxygen consumption*

Analysis of oxygen consumption yielded significant differences. Results are presented in Table 3. Oxygen consumption values were significantly higher (F (1, 18) = 7.7, p = .01) during the pole trial (29.8 ± 2.6 ml/kg/min) compared to the non pole trial (28.6 ± 2.8 ml/kg/min) and remained after adjusting for covariates. Data for oxygen uptake averaged over five minute periods were also explored. As shown in Figure 1, visual observations of each time point exhibit lower specific rates for $VO_2$ in the no pole condition, which were statistically significant at the 10 and 20 minute time points (p =.002 and p = .03, respectively).

*Total energy expenditure*

Results from the repeated measures ANOVA revealed that TEE was significantly higher (F (1, 18) = 11.4, p = .003) in the pole condition (223.3 ± 57.9 kcals) compared to the no pole condition (209.6 ± 47.7 kcals); results are presented in Table 3. Differences in TEE after adjusting for weight and other covariates remained strong (F (1.17) = 8.3; p = .01).

*Non protein respiratory exchange ratio*

No significant differences in mean RERs were observed across the conditions (.94 ± .05 P vs. .93 ± .05 NP) with and without adjusting for covariates. Non protein respiratory exchange ratio response patterns during the 1.68 km hiking trial are displayed in Figure 2 for both conditions. Although, upon visual inspection there was a tendency for the pole users to elicit higher RERs, RER was not found to be significantly different between the two conditions at any singular time point examined.

*Heart rate*

No significant effect for mean heart rate was observed, with averages in the pole condition and no pole condition being 151.3 ± 19.6 bpm and 147.7 ± 19.9 bpm, respectively. Heart rate was not found to be significantly different between the two conditions at any singular time point examined, although the tendency was for pole use to elicit a higher heart rate over the 1.68 km distance. Results are illustrated in Figure 3.

*Rate of perceived exertion*

No significant differences were observed in mean RPE in both non-parametric ($p = .52$) and parametric ($F (1, 19) = .281$, $p = .60$) tests (Table 3). Differences in RPE at each five minute collection period were also examined, although there was a propensity for the pole condition to elicit a greater RPE response, there was no significant effect of condition at any of the time points examined. Results are illustrated in Figure 4.

## Chapter 5

## Conclusion

This study was designed to determine the metabolic, cardiovascular, and RPE responses of hiking with poles under field conditions. The primary findings of this study were that the use of hiking poles increased physiological variables at a given speed, without increasing the hiker's RPE. More specifically, data from this study indicated that when hiking at a self selected pace, over a 1.68 km trail (average 12.6% grade), average oxygen consumption and energy expenditure were 13.7 kcals and 1.2 $ml \cdot kg^{-1} \cdot min^{-1}$ greater when hiking with poles than when hiking without poles. The elevated oxygen consumption and consequential increase in energy expenditure that was observed while hiking with poles reveal an increase in the energy cost of hiking, without increasing the intensity level, heart rate, RPE or time to completion.

*Oxygen consumption and total energy expenditure.*

The present study provides additional evidence to support that the use of hiking poles during uphill hiking leads to an increase in total energy cost. Previous researchers have examined similarities between exercising with hand weights and walking with poles. Maud et al., (1990) found that at a constant speed, carrying 1.36 kg hand weights would increase the oxygen cost of exercise at a speed of 6.4 km/hr on a level treadmill. Maud and colleagues also found that a vigorous arm swing alone was sufficient to increase the oxygen cost of exercise compared to that of walking without vigorous arm swing or hand held weights at a constant speed. These results are similar to Graves et al.'s (1987) findings of increased oxygen uptake when hand held weights (1.36 kg) were added to walking at a constant speed and grade. However, Foissac, et al., (2008) found that the actual mass of hiking poles (measured up to 360 grams/pair) did not influence the energy cost of hiking on a treadmill inclined at 20 % at 3 km/hr, but walking with increased step frequency, rather than preferred or low frequency, did. The hiking poles in the present study were .68 kg and a natural arm swing was encouraged; it may be more likely that the weight of the poles and/or swing of the arm was not responsible for the increased oxygen consumption during the uphill ascent, but rather the distribution of muscular activity from the lower body and increased activation of upper body musculature that may explain any increases in oxygen consumption.

In this present study, a small, yet significant (4.2 %) increase in oxygen consumption was found with the use of hiking poles. Previous research in both field and lab settings has found between a 10 to 23 % increase in oxygen consumption with the use of hiking, Nordic, trekking, and/or walking poles (Saunders et al. , 2008; Sklar et al., 2003; Rodgers et al., 1995; Duncan, & Lyons, 2000; Porcari et al., 1997). The greatest difference in oxygen uptake are from lab studies in which pole use was intended for increasing overall energy expenditure for exercise (Porcari et al., 1997; Rodgers et al., 1995). The resultant increase in energy expenditure in this study (6.5%) was found with the use of hiking poles. Sklar and colleagues (2003) found similar increases in TEE (6.3%), as well as, an increase in oxygen consumption in the pole condition while hiking a distance of 2 km, uphill (9 % grade) at a self-selected pace and intensity; however, Duckham and colleagues (2009) found no significant differences in TEE in a field setting in which participants hiked uphill, at maximal effort for 4.42 km. Duckham and colleagues' (2009) protocol called for maximal effort by participants in pole and no pole conditions, which may explain the different findings.

Other research has found that maximal effort and higher speeds may minimize differences in TEE in pole vs. no poles. It may be that at faster speeds, the arm must be swung more vigorously to maintain that pace, resulting in increased oxygen consumption. During pole use at faster speeds, cycle rates are reduced and the propulsive phase time is decreased; therefore, variances in oxygen consumption between pole conditions may be minimized. At slower speeds, the differences in energy cost between conditions may be more pronounced; vigorous arm swing is not necessary to maintain a slower pace as this would result in less energy utilization.  Pole use at a slower pace would produce cycle rates that are longer, which may allow the recruitment of additional upper body musculature for the propulsive phase. This increase in active muscle mass would result in an increase in energy expenditure, making the differences between pole conditions at slower paces more pronounced. These findings are in line with Foissac et al., (2008) who discovered that at low frequency walking speeds (20 % incline), the use of poles reduced the activation of lower limb musculature by 15 % and increased upper limb muscle activation by 95 % without increasing oxygen consumption. High frequency walking conditions exhibited a significantly greater average increase in oxygen consumption compared to both low and preferred frequencies; however, low frequency walking was greater, although not significantly, than the preferred frequency walking condition. These results indicate that the reduced loading of the lower extremities found with pole use may lessen localized fatigue at low and preferred speeds and that preferred pace may be optimal for minimizing overall energy cost per distance traveled.

The present study's findings of an increase in oxygen consumption associated with pole use, as well as, other studies conducted at grades less than 15% and self-selected pace, may be explained by the additional recruitment of upper body musculature during the pole condition. The grade of the present study was 12%; it is possible that at higher grades, the cost of carrying the poles is offset. Previous research suggest that the use of hiking poles may not lead to an increased energy cost at grades greater than 15%, as no significant differences were found in oxygen consumption in studies conducted in the field or lab (Perrey, & Fabre, 2008; Foissac et al., 2008; Jacobson, Wright, & Dugan, 2000; Jacobson, & Wright, 1998). The energy exchange between potential and kinetic energy to reduce metabolic energy expenditure does not occur at grades greater than 15% (Minetti, Ardigò, & Saibene, 1993) because little can be done to reduce the overall mechanical work when all the work is done to lift the body mass each step; however, it appears that with hiking pole use, a transfer of some of the work done by the legs is redirected to the upper body to aide in lifting the body mass in step to step transitions. This could lead to a decrease in localized fatigue in the lower body and benefit hikers during prolonged mountain ascents.

*Heart rate*

Although the metabolic demand was greater as evident by an increase in oxygen consumption and total energy expenditure, the cardiovascular demand, although not significantly different, did demonstrate a trend to be slightly higher with pole use. These results are in line with previous studies conducted in both lab and field settings (Rodgers et al., 1995; Jacobson, Wright, & Dugan, 2000; Duckham et al. 2009; Perrey & Fabre, 2008; Sklar et al., 2003) that found no significant differences in heart rate. However, lower specific rates in the no pole condition were found for most of the heart rate time points examined. As found by earlier research on upper body and combined upper body and lower body exercise (Hoffman, Kassay, Zeni, Clifford, 1996; Toner, Sawka, Levine, & Pandolf, 1983)data suggests that the increased oxygen consumption associated with an increase in the activation of upper body musculature was not accompanied by an elevated heart rate response when at least 40% of the power output was performed by the lower body, and higher heart rate values occurred when more total work was performed by the arms (Toner, et al., 1983). Toner and colleagues believed this may be attributed to an increased venous return and/or a decreased total peripheral resistance. As the amount of muscle mass that is recruited for work increases, a greater venous return is facilitated and a smaller heart rate response is elicited for the same relative exercise intensity. The increased $VO_2$ found in this study may be best explained by an increase in oxygen extraction from active muscle as heart rates between conditions were not significantly different and stroke volumes are thought to plateau at relatively low exercise intensities (40 to 60% of maximal capacity). Although maximal exercise capacity ($VO_2$ max) was not assessed in this study, high RER values indicate that the participants were working at higher intensity levels.

*Rate of perceived exertion*

This was the first field study on hiking pole use to collect RPE over time as is done in laboratory settings, as all previous field research collected RPE at the end of each hiking trial. This allowed for analysis of change in RPE over time. Although RPE was not significantly different across conditions, the trend in the previous study as well in the literature reviewed (Duckham, et al., 2009; Duncan, & Lyons, 2008) is for RPE to be lower when hiking with poles compared to hiking without poles (Jacobson, & Wright, 1998; Jacobson, Wright, & Dugan, 2000; Knight, & Caldwell, 2000; Sklar, DeVoe, & Gotshall, 2003). Subjects in this study were expending more energy in the pole condition, yet they perceived there to be no difference between conditions.

The current study's RPE results support research on upper body and combined upper and lower body exercise by Hoffman and colleagues (1996) who found that the distribution of work between the arms and legs during cycling allowed individuals to exercise at higher heart rates and power outputs for a given RPE than when all the work was performed by the legs. Hoffman et al. (1996) posited that the distribution of work over a larger mass of muscle would reduce the sensory input for RPE from sensations of strain in the working muscles. Similar results were found for uphill roller skating using the double poling technique and diagonal stride technique at a 7.1 % incline. The RPE was lower for the diagonal stride technique despite oxygen consumption values being similar. What was found was that the oxygen consumption for a given RPE was higher for the cross country skiing technique using the larger muscle mass (Hoffman, Clifford, Watts, Phillip, Drobish, & Gibbons, et al., 1994). It may be that as the work performed by the lower body is partially distributed to the upper body there is a lessened feeling of localized fatigue of the lower body musculature.

*Non-protein respiratory exchange ratio*

Exercise intensity as measured by RER was not significantly different between the pole and no pole condition, although RER was slightly higher in the pole condition. These results are similar to Perrey and Fabre (2008) who found no significant differences in RER between conditions. It appears that based on the data available, the magnitude of change in the RER response may be decreased as grade increases, similar to TEE findings. This is in agreement with findings by Rodgers et al., 1995, as well as, Porcari et al., 1997 who found a 5 and 10 % increase in RER, respectively. The protocols in these studies used motorized treadmills set at 0% grade and used poles as a way to increase the intensity of exercise rather than as a means of alleviating fatigue in the lower body. Subjects in study by Rodgers and colleagues (1995) remained in a fat burning range (RER .78 ± .04 no pole vs. .82 ± .03 pole condition) in both conditions and subjects in Porcari and colleague's study demonstrated the greatest increase in intensities from no pole to pole condition(.85 ± .09 no pole vs. .93 ± .05 pole).

The current study had several limitations. First, the present study had only 20 participants and power calculations were based on a study for 32. A larger sample may be needed to confirm these results and differences in RPE and duration. Secondly, upper body power and endurance may be a limiting factor for novice pole users seeking an increase in performance while using hiking poles and may explain the lack of significant differences in time to completion between pole conditions in this study and others conducted in the field (Sklar et al., 2003; Duckham et al, 2009). A pre-trial assessment of upper body strength (1-rep max) may be advantageous for future researcher in order to examine any correlations between upper body strength and hiking pole performance. Thirdly, unfamiliarity with pole use may have prevented the participant from making any significant upper body contributions to the work performed, while maximizing any benefits (decreased RPE, and energy cost) of their use, as the novice pole user may be less effective in muscular utilization and energy conserving techniques than an expert. Future research examining the energy cost of pole use between novice and experts would be beneficial, as well as, in novice after extended training sessions. In physically active but non-arm trained subjects, a low oxygen extracting capacity has been reported (Gonzalez-Alonso, & Calbet, 2003), as compared to highly trained individuals, such as cross country skiers, who have increased capillary density in the arms, allowing for increased oxygen extraction and increased performance in the form of oxygen consumption. This allows for higher intensity performance to be sustained for longer periods of time and is why cross country skiers have the highest values for oxygen consumption. As Minetti, Formenti and Ardigò (2006)reported after studying Himalayan porter's performance on steep mountainous treks, maintaining speeds during uphill hiking conditions depend on sustaining maximal metabolic power and the decreased metabolic cost of movement associated with highly trained individuals.

This study was also short-term. The effects of hiking pole use have generally only been measured for a short period of time; familiarization, prolonged use and fatigue are likely to change the way the poles are utilized during hiking; therefore, future studies of prolonged duration are necessary to determine the physiological changes and perceived effort that occur with their use.

This study could not tightly control environmental conditions; however, every effort was made to test at similar times of the day. The recreational use of the testing trail could not be restricted; therefore, participants had an occasional run in with other hikers, mountain bikers and wildlife. Field studies may not be as tightly controlled as laboratory studies, but may have a more direct application for hikers, backpacker and mountaineers. More uniform protocols in field conditions may help future researchers discover the cost of hiking pole use during continuous uphill hiking.

In summary, the purpose of this study was to investigate the physiological effects and rate of perceived exertion response for hiking pole use during continuous uphill hiking. As pole use becomes more popular with hikers as a means of adding stability and easing the stresses on the lower body, the question of their cost becomes more important. For hikers, the ability to offset fatigue increases the amount of time and distance spent hiking. While physical fitness and genetic potential ultimately shape capabilities, the use of poles may aid hikers to overcome adjustments in locomotion that occur at greater inclines.

As of now, these findings suggest that the use of hiking poles increases the physiological demand for fit, recreational hikers during uphill hiking at self-selected speeds without increasing RPE.

Future research with a larger sample size, fatigue inducing duration, as well as, an expert and novice pole use group would be advantageous to fully evaluate how the energy cost and perception of exertion associated with hiking pole use is altered at mountain grades greater than and less than 15 %. Baseline testing of resting heart rate and maximal oxygen consumption would be beneficial in reducing variability of physiological responses. Additionally, research examining muscular utilization and propulsive forces exerted by the upper body at grades greater and less than 15 % in novice and expert populations would be of assistance in quantifying the transfer of work from the lower body to the upper body and may assist in identifying energy conserving techniques.

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Table 1.

Participant characteristics (N=20)

| | Men (n=10) | Women (n=10) | Mean ± SD |
|---|---|---|---|
| Age (years) | 22.5 ± 2.2 | 22.8 ± 1.9 | 22.7 ± 2.0 |
| Height (cm) | 182.2 ± 5.3 | 162.2 ± 5.6 * | 172.2 ± 11.5 |
| Weight (kg) | 85.2 ± 17.9 | 61.9 ± 5.1 * | 73.5 ± 17.5 |
| BMI (kg/m$^2$) | 25.6 ± 4.7 | 23.5 ± 1.7 | 24.5 ± 3.6 |
| % Hiking Experience | 40 | 10 | 25 |
| % Hiking Pole Experience | 0 | 0 | 0 |
| Enjoy Hiking | 5.7 ± 1.6 | 5.7± 0.9 | 5.6 ± 1.3 |
| Enjoy Physical Activity | 6.5 ± 0.9 | 6.3 ± 0.7 | 6.4 ± .9 |

Enjoyment of hiking and physical activity are rated on a 1-7 scale, where 1 = not at all and 7= extremely enjoy.

* Indicates significant difference ($p \leq .001$).

Table 2.

**Self-reported sleep, fatigue and vigor prior to each testing condition.**

| | Pole Condition<br>Mean ± SD | No Pole Condition<br>Mean ± SD |
|---|---|---|
| Sleep (hours) | 7.6 ± 1.5 | 7.7 ± 1.8 |
| Pre-hike fatigue | 2.8 ± 1.4 | 2.9 ± 1.2 |
| Pre-hike vigor | 4.9 ± 1.0 | 5.1 ± 0.8 |

Fatigue and vigor are rated on 1-7 scale, where 1= not at all and 7= extremely or endless amounts. No significant differences between pole conditions.

Table 3.

Physiological responses to hiking with and without hiking poles

| | Poles Mean ± SD | No Poles Mean ± SD | Within Group |
|---|---|---|---|
| Duration (min) | 20.2 ± 1.3 | 20.0 ± 1.4 | $F(1,19)=.53$, $p=.48$ |
| RPE | 10.8 ± 2.0 | 10.6 ± 1.7 | $p=.52$ non parametric<br>$F(1, 19) = .281$ RM ANOVA |
| $VO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | 29.8 ± 2.6 | 28.6 ± 2.8 | $F(1,18)=7.7$, $p=.01$ |
| RER | .94 ± .05 | .93 ± .05 | $F(1,18)=.751$, $p=.40$ |
| HR (bpm) | 151.3 ± 19.6 | 147.7 ± 19.9 | $F(1,18)=2.48$, $p=.13$ |
| TEE | 223.3 ± 57.9 | 209.6 ± 47.7 | $F(1,18)=11.4$, $p=.003$ |

RPE= rate of perceived exertion based on Borg's scale of 6-20. TEE= total energy expenditure. HR= heart rate. Unadjusted results are presented.

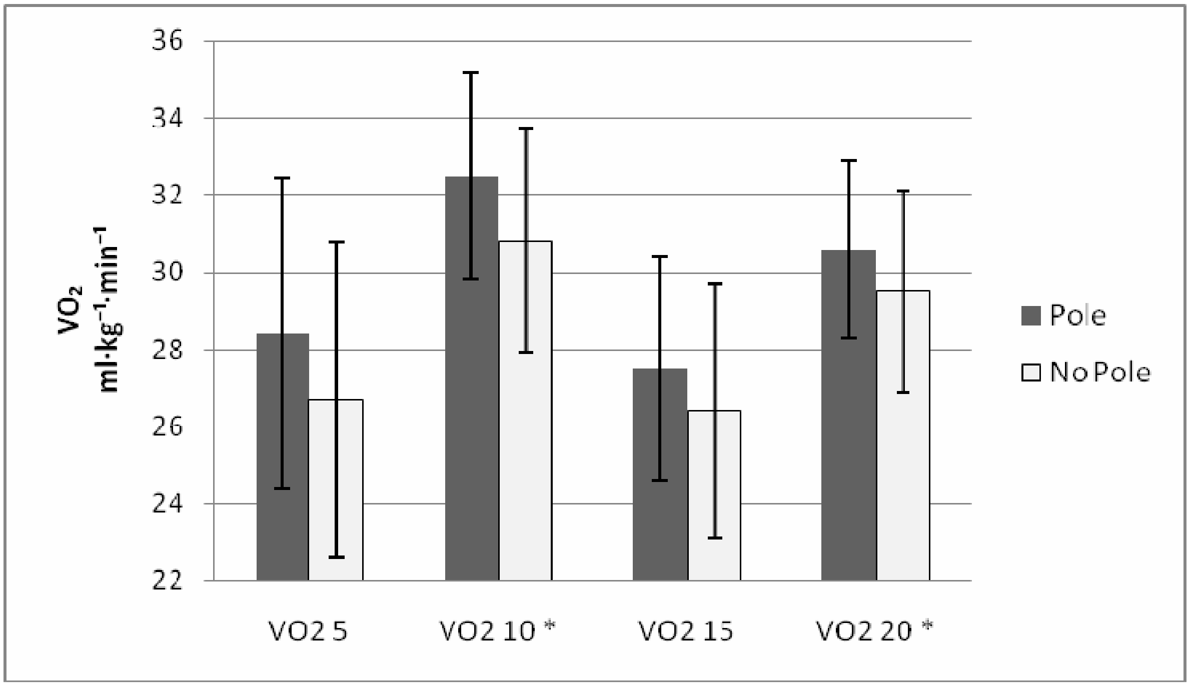


Figure 1. Mean VO□ by pole condition
VO□ 5 = mean oxygen consumption for minutes 0-5; VO□ 10 = mean oxygen consumption for minutes 5-10 *(p = .002); VO□ 15 = mean oxygen consumption for minutes 10-15; VO□ 20 = mean oxygen consumption for minutes 15-20 *(p = .03).

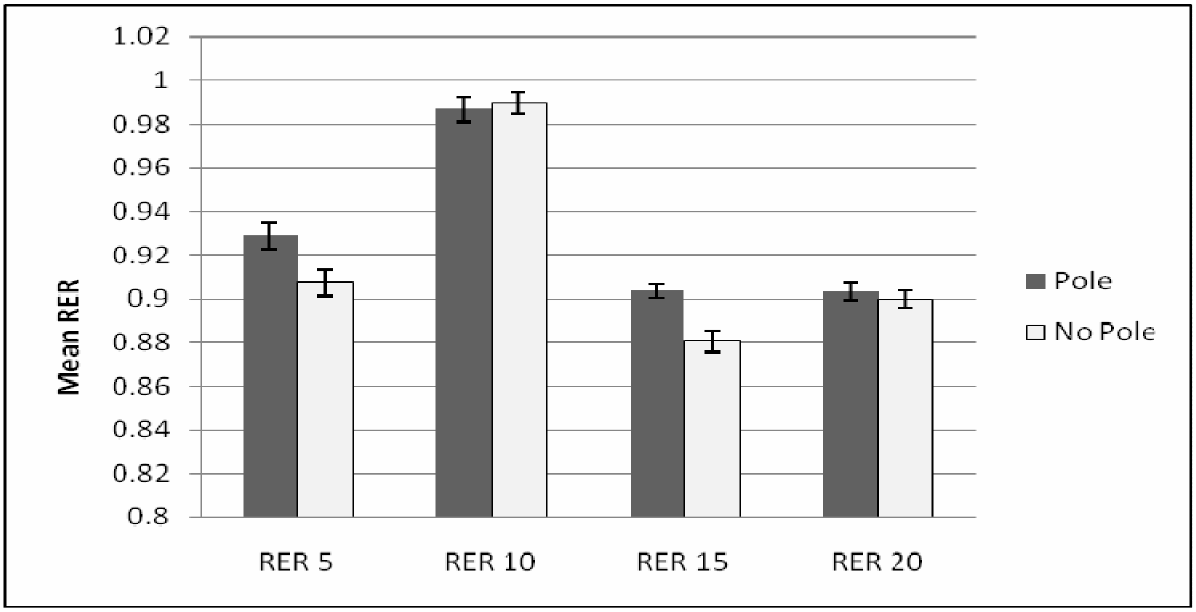


Figure 2. Mean RER by pole condition
RER 5= mean RER for minutes 0-5; RER 10= mean RER for minutes 5-10; RER 15= mean RER for minutes 10-15; RER 20= mean RER for minutes 15-20.

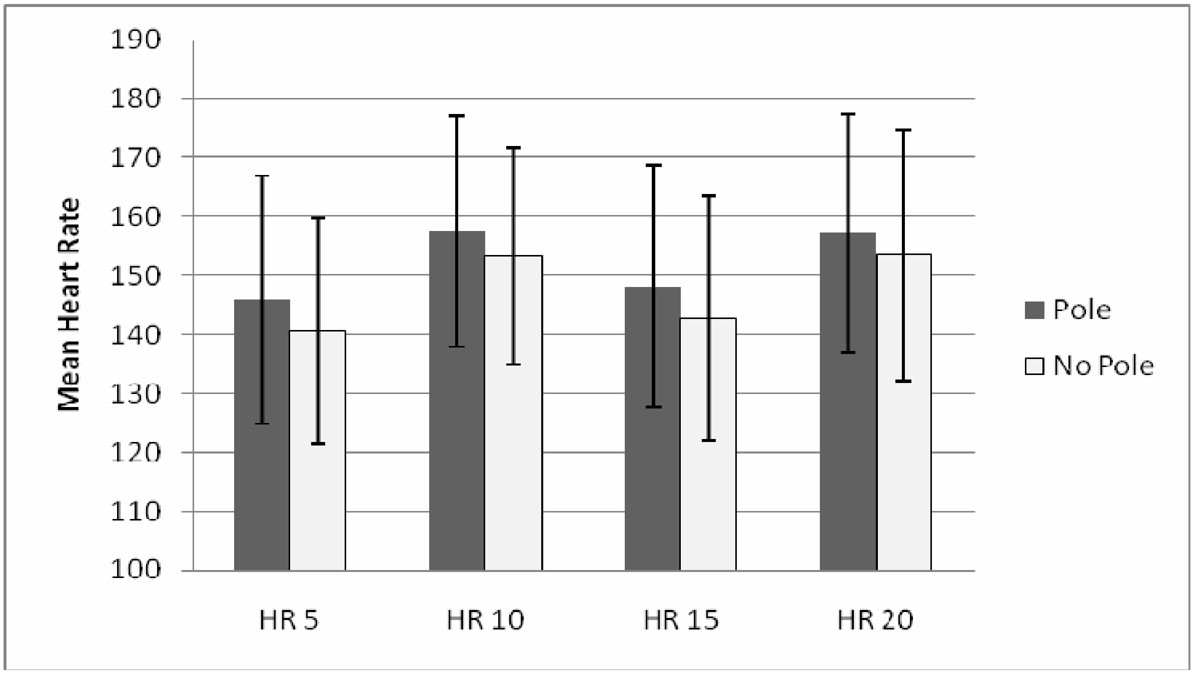

Figure 3. Mean HR by pole condition
HR 5 = mean heart rate for minutes 0-5; HR 10 = mean heart rate for minutes 5-10; HR 15 = mean heart rate for minutes 10-15; HR 20 = mean heart rate for minutes 15-20.

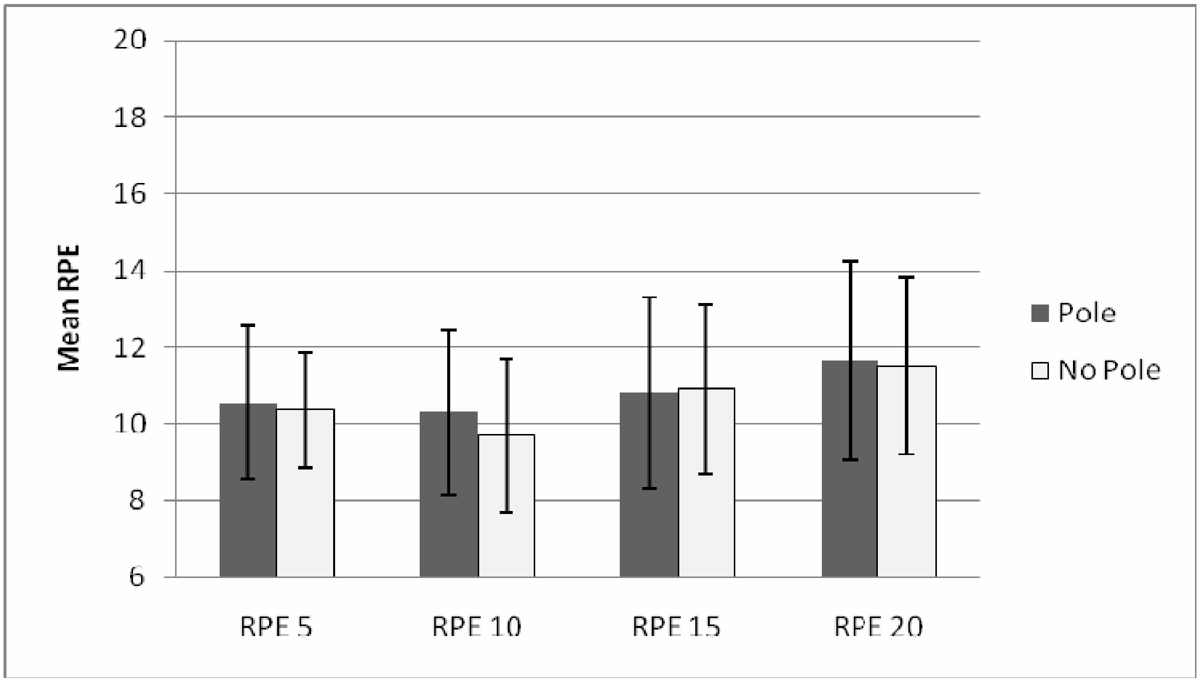

Figure 4. Mean RPE by pole condition
RPE 5=mean RPE for minutes 0-5; RPE 10= mean RPE for minutes 5-10; RPE 15= mean RPE for minutes 10-15; RPE 20= mean RPE for minutes 15-20.

Appendix A

## Informed Consent to Participate in Effects of Hiking Pole Use While Uphill Hiking Study

A research project on the effects of hiking pole use is being conducted by Sunny Atchison in the Department of Kinesiology at Cal Poly, San Luis Obispo. The purpose of this study is to determine the benefits of using hiking poles during continuous uphill hiking.

You are being asked to take part in this study by 1) completing a Physical Activity Readiness questionnaire with additional screening questions to determine willingness to participate and eligibility (you may omit any items you prefer not to answer on this questionnaire), 2) allowing your height, weight, resting and exercise heart rate, rate of perceived exertion and oxygen consumption to be measured and 3) by completing 24 hour diet and physical activity recalls before each testing session.

Your participation in this study will require 3 separate sessions of approximately one hour in length. The first session after the initial screening will involve height, weight and resting heart rate measurements as well as training on pole use, pre-testing protocols and familiarization with testing procedures. The second and third session will be scheduled based on your availability and will involve measurements of resting heart rate and a short review on correct hiking pole technique if using hiking poles that day. There will be at least 48 hours between testing trials for the same individual. The VmaxST portable metabolic device will be attached to you during testing. The machine weighs less than 3 pounds and will be placed over your shoulders, like a vest. You will be wearing a head cap that will support the mouthpiece you will be breathing into; a nose clip will also be required. Please be aware that you are not required to participate in this research and may discontinue your participation and anytime without penalty.

The possible risks associated with participation in this study include discomfort and possible fatigue associated with 30 minutes of moderate physical activity. Discomfort (e.g., dry mouth) while wearing mouthpiece and nose clip is minor. Muscle soreness the day after is possible. If you have concerns about the testing methods or procedures, please be aware that you may contact the researcher, Sunny Atchison, at any time at satchiso@calpoly.edu or (805) 756-5367 for assistance.

Your confidentiality will be protected. Your name will not be used during testing. Your name will be replaced by a number I.D.  Access to all screening questionnaires and contact information will be limited to the primary researcher. All data with participant's private your information will only be accessed by the primary researcher and be kept separate from data collected during the trials. The results may be presented as group data, but your name will not be linked to specific results in discussion or presentations about this study.

If you have questions regarding this study or would like to be informed of the results when the study is completed, contact Sunny Atchison at (805) 756-5367 or email satchiso@calpoly.edu. If you have questions or concerns regarding the manner in which the study is conducted, you may contact Dr. Steve Davis, Chair of the Cal Poly Human Subjects Committee, at 756-2754, sdavis@calpoly.edu, or Dr. Susan Opava, Dean of Research and Graduate Programs, at 756-1508, sopava@calpoly.edu.

If you agree to voluntarily participate in this research project as described, please indicate your agreement by signing below. Please keep one copy of this form for your reference, and thank you for your participation in this research.

____________________________ ____________________________

Signature of Volunteer Date

____________________________ ____________________________

Signature of Researcher Date

## Appendix B

## Screening Questionnaire

Sunny Atchison is seeking students to participate in a study to better understand the use and effects of hiking poles. Participation would require attendance at three separate sessions of up to 1 hour each. Testing will be scheduled based on availability and will occur over a period of 8 weeks. Participation is completely voluntary. If you would like to learn more about the study, please complete the following questions below. If you are eligible, we will contact you to provide more information.

1. Name:

2: Age:

3. Sex (Circle response) Male or Female

4. Phone number or email (preferred contact method):

5: Are you on a competitive sport's team at Cal Poly? (Circle response) Y or N

6. Are you currently training for sports performance? (Circle response) Y or N

7. How many days a week do you workout and how many minutes each day?

8. What type of outdoor recreational activities do you enjoy (including sports) and how often do you participate in them?

9. Have you ever been hiking? Y or N

10. How many times in the past year have you been hiking for more than 30 minutes?

11. Would you consider yourself an expert or regular hiker? Y or N

12. Do you use hiking poles while hiking? Y or N

13. How many times in the past year have you used hiking poles?

14. Due to the fact that certain medications alter exercise response it is necessary for you to list any prescribed or over the counter medications.

## Appendix C

## Pre Testing Questionnaire

Participant ID:

Testing Day: 1 or 2; P or NP

Date:

Time:

1. How many hours of sleep did you get last night?

2. How tired do you feel right now? On a scale from 1-7, 1=not at all and 7=extremely tired (circle one)

1……….2……….3……….4……….5……….6……….7
(Not at all) (Extremely)

3. How much energy do you have right now? On a scale from 1-7, 1=none and 7=endless amounts (circle one)

1……….2……….3……….4……….5……….6……….7
(None) (Endless amount)