AN ABSTRACT OF THE THESIS OF

Kari L. Birdsley for the degree of Master of Science in Exercise and Sport Science presented on June 6, 2005.

Title: Estimation of the Energy Cost of Walking 10,000 Steps.

Redacted for Privacy

Abstract approved: ______________________

Anthony R. Wilcox

There is a strong campaign underway to promote increased physical activity among the U.S. population. The U.S. Surgeon General and the U.S. Dietary Guidelines have presented physical activity recommendations in terms of the amount of time accumulated in physical activity and/or in terms of energy expenditure over the course of a day. Another approach that has been widely promoted is the goal of accumulating 10,000 steps a day, as monitored by a pedometer. The purpose of this project was to evaluate the estimated energy expenditure of walking 10,000 steps, and to determine the distance covered and time required to do so, as extrapolated from a 30-minute walk test. The current study also compared males and females on these variables to determine if gender differences were present.

Energy expenditure was determined by indirect calorimetry from steady-state oxygen consumption during 30 minutes of walking on a treadmill at a self-selected pace while wearing Yamax Digiwalker DW-201 pedometers

at the hip. The subjects consisted of 18 males and 20 females who averaged 22.3 years of age and a BMI of 25.5. A one-way analysis of variance was used to test for any gender differences in relation to walking pace, step count, steps per kilometer, and energy expenditure expressed as: kilocalories per kilometer per kilogram body weight, kilocalories per minute per kilogram body weight, and kilocalories per 10,000 steps.

The self-selected walking pace of the subjects averaged 76.8 m/min, and they averaged 3191 steps in the 30-minute session. At that rate, it would require 94 minutes to complete 10,000 steps. There were no significant differences in levels of energy expenditure between males and females when expressed per minute, per distance, or per 10,000 steps. The males and females averaged 507±235 kcal/10,000 steps across all subjects. The distance covered in 10,000 steps averaged 7.2±2.0 kilometers for all subjects, with no differences between males and females. The current study demonstrates that the recommendation to achieve 10,000 steps per day would exceed the minimum recommendation for physical activity given by the U.S. Surgeon General, while achieving the level of physical activity recommended for reducing body weight by the latest U.S. Dietary Guidelines.

Estimation of the Energy Cost of Walking 10,000 Steps

by

Kari L. Birdsley

A THESIS

submitted to

Oregon State University

in partial fulfillment
of the requirements for the
degree of

Master of Science

Presented June 6, 2005
Commencement June 2006

Master of Science thesis of Kari L. Birdsley presented on June 6, 2005

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I understand that my thesis will become a part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

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Kari L. Birdsley, Author

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to the family, friends, and faculty who have helped to ensure the completion of this project. It has been a long time in coming but with continued support and encouragement from those around me I was able to persevere and complete my thesis.

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DEDICATION

This thesis is dedicated to my mother and the loving memory of my father.

Estimation of the Energy Cost of Walking 10,000 Steps

INTRODUCTION

The benefits of physical activity on one's health have been extensively studied and examined over the past century. The amount and extent of physical activity one must engage in to attain these desired health benefits is still currently under investigation and continues to be debated. However, there is a consensus among those in the health field that habitual physical activity has a positive effect on one's physical well being. The American College of Sports Medicine (ASCM) has categorized these benefits into four main areas: [1] improvement in cardiorespiratory function, [2] reduction in coronary artery disease risk factors, [3] decreased mortality and morbidity, and [4] other postulated benefits such as: decreased anxiety and depression and/or enhanced performance at work (1).

Physical inactivity is a widespread problem in the United States today. As a result, the ACSM (1) and the U.S. Surgeon General (2) have published exercise guidelines. However, a clear distinction has been established between physical activity ("any bodily movement produced by skeletal muscles that results in energy expenditure") and exercise ("as a sub-category of physical activity defined as planned, structured movement undertaken to improve or maintain one or more aspects of physical fitness") (3).

The value of walking as a form of physical activity or exercise tends to be underestimated. A couple possible explanations for this is because walking is an activity that many individuals naturally engage in everyday. Another is due to its relatively low intensity when compared to more strenuous activities like running or cycling. However, a major benefit to walking is the fact that it is a relatively simple activity which the majority of individuals can perform throughout their entire life. This ability to maintain walking as a lifelong activity could potentially lead to greater adherence as individuals are able to incorporate walking into their daily life. This parallels the U.S. Surgeon General's activity guidelines promoting an accumulation of 30-minutes of moderate intensity activity on most, if not all, days of the week (2). Current guidelines, though established in the 1990's, still focus on a lifestyle approach to physical activity by incorporating a broader range of activities, like walking and household chores, that count towards one's overall activity for the day. The intention behind these guidelines is to promote more physical activity (both leisure and non-leisure) among the nation's sedentary population. It is hoped these guidelines will appear less intimidating by encouraging this lifestyle approach and by including and promoting a wider variety of activities. The U.S. Dietary Guidelines for 2005 recommend "engaging in regular physical and reducing sedentary activities to promote health, psychological well-being, and a healthy body weight." The U.S. Dietary Guidelines also recommends 30-minutes of moderate physical activity most days of the week to reduce chronic disease, and 60-90 minutes of moderate to vigorous physical activity most days of the week to maintain or lose weight (4).

Relatively inexpensive pedometers have been shown to accurately record one's steps while walking, resulting in their being used to quantify daily physical activity and to motivate people to achieve certain targets, such as 10,000 steps per day (5-9). A goal of 10,000 steps originated in Japan with the use of the step meter pedometer. Its nickname "mano-pei" literally means 10,000-steps-meter. It was a means of promoting activity to counteract sedentary urban living (10). Numerous studies have assessed the energy cost of walking relative to distance covered and report an expenditure of between 3.0-7.4 kilocalories per minute depending on walking speed (11-14): however, few have related energy expenditure to step count.

Previous research has evaluated whether subjects achieved 30-minutes of moderate physical activity if they walked 10,000 steps in a day (15) or how many steps they would walk in 30-minutes (16). The primary focus of the current study was to determine, through indirect calorimetry, the energy cost of walking as it relates to step count. Based on 30-minutes of level walking, the current study will estimate energy expended in 10,000 steps as well as the distance covered in 10,000 steps. A secondary purpose of the current study was to compare males and females for these variables and note any gender differences.

METHODS AND PROCEDURES

Subjects

A total of 38 male and female adults (18 males and 20 females) were recruited through announcements in classes on campus as well as by flyers posted around the university. Each subject was given an explanation of the nature of the study along with the general procedures, and each signed an informed consent form prior to participating in the study. Each subject was also administered a PAR-Q: The Physical Activity Readiness Questionnaire (17) to screen for her/his suitability to participate in the study. The study was approved by the Oregon State University Human Subjects Institutional Review Board.

Instruments/Apparatus

The height (ht) of each subject was measured using a wall stadiometer and weight (wt) was assessed to the nearest 0.5kg using an Accu-weigh ™ scale. From this data, body mass index (BMI) was calculated. The leg length (LL) of each subject was assessed by measuring the distance from the anterior superior iliac spine to the medial malleolus with a spring-loaded tape measure (18, 19). Step count was recorded by a Yamax Digiwalker, DW-201 (Tokyo, Japan) that was worn on both the right and left hips. The DW-201 was selected for the current study due to the reported accuracy of Yamax Digiwalkers (5, 8, 9). The subject's oxygen consumption through the entire duration of the walking trial was measured using a Sensormedics 2900 metabolic cart. Heart rate (HR) was monitored using a Polar heart rate monitor and was recorded at minutes 0, 5, 10, 20, and 30. A rating of perceived exertion (RPE) was also recorded at minutes 5, 10, 20, and 30. According to the RPE scale: 9 is "very light," 11 is "fairly light," and 13 is "somewhat hard" (20). Twelve is the last number before the word "hard" is used as a part of the description. For this reason, the RPE of 12 was made the cutoff point for the current study. The average of each subject's HR and RPE values across the four recording times were used to determine the subject's overall HR and RPE for the walking trial.

Experimental Design

The primary objective of the current study was to estimate the energy cost of walking 10,000 steps on a level treadmill, extrapolated from 30-minutes of level walking. The subjects reported to the OSU Human Performance Laboratory wearing shorts, T-shirt, and comfortable walking shoes. The initial evaluation included collection of general demographic information, height, weight, and leg length. Demographic information included: age, gender, ethnicity, and current exercise habits. The subjects were given an opportunity to ask any questions they might have had before the testing procedures began.

The subjects walked at a self-selected pace; they were instructed to walk purposefully, rather than merely strolling along. The subjects were provided an opportunity to walk on the treadmill and become familiar with its use. As this was being accomplished, a comfortable walking speed was determined and this three-to-five-minute adjustment period served as the subject's warm-up period. Prior to the onset of the actual walk test, but after the warm-up, the subject's HR was recorded at time zero. This initial HR served as a beginning value and allowed the researcher to track each subject's HR increase in response to the exercise.

Once the subjects had achieved a steady state for exercising (comfortable walking speed and HR that had plateaued), the test began. The subjects were asked to straddle the treadmill while the pedometers on each hip and the clock were reset to zero. The subjects then began their 30-minute trial walking on the treadmill at their own self-selected pace. The actual speed of the treadmill was verified and recorded using a digital tachometer during the test. At the conclusion of 30-minutes, the subjects were once again instructed to straddle the treadmill as the counts on the pedometers were recorded. Once all of the final data had been collected, the subjects were allowed to cool down.

The subject's oxygen consumption was measured continuously by a Sensormedics 2900 metabolic cart throughout the entire 30-minute exercise test. The measurement of oxygen consumption allows for the calculation of energy expenditure. The total energy expenditure (kilocalories) was determined for the 30-minute trial. The distance covered was calculated based upon the recorded treadmill speed. Energy expenditure was extrapolated and expressed on the basis of steps (kilocalories/10,000 steps) and distance (kilocalories/kilometer). In addition, the distance per 10,000 steps was also extrapolated.

Statistical Analysis

The primary aim of the current study was descriptive, in that it related energy expenditure to pace and step count while walking. The secondary aim was to determine if gender differences existed in the self-selected walking pace or in step count and cadence. A t-test was performed to see if there was a significant difference between the recorded step counts for the right and left hips. A Pearson Correlation was also performed to determine the level of correlation between the right and left hips. A correlation matrix was generated to test for any potential correlations between any of the variables collected or calculated. A one-way analysis of variance was used to test for any gender differences. The alpha level for the analysis of variance was set at .05. A power of 0.80 had also been established for the current study. A sample size of 30 (15 males and 15 females) was determined by the procedures described by Kirk (21). The effect size for the current study was predicted to be medium, since a moderate increase in energy expenditure could have significant health benefits. There were additional subjects recruited and tested for each group (19 males and 23 females).

In the current study, energy expenditure per kilometer, energy expenditure per 10,000 steps, and steps per kilometer were assessed for both males and females separately. Based on the collected values for 30-minutes and the calculated values, the overall energy expenditure was extrapolated to the goal of 10,000 steps per day. A final comparison was used to determine if any significant gender differences existed. The statistical package used in the analysis of the data was JMP-IN, 3.0 for Windows (1997, SAS Institute, Cary).

RESULTS

There were a total of 42 subjects tested during the current study, 19 males and 23 females. However, only 20 female and 18 male subjects were used during the statistical analysis of the data. Four subjects were removed from the final analysis due to the following reasons: the RPE reported was too high (not a moderate value for two female subjects); one male subject held onto the treadmill rails for a portion of the test; and one female test subject's nose clip fell off during the actual walk test, affecting the accuracy of the oxygen consumption recorded.

The subjects had a wide range of self-reported exercise habits. This would potentially lead to a broad span of fitness levels. Two subjects (one male and one female) did not exercise at all and another male subject exercised six to seven days a week for two to four hours. All subjects appeared to be healthy with no known risk factors. Table 1 summarizes the physical characteristics of the 38 test subjects.

Table 1. Physical Characteristic Data (mean ± SD)

	n	Age (yrs)	Ht (cm)	Wt (kg)	LL (cm)	BMI (kg/m2)
Males	18	22.2 ± 7.4	179.9 ± 8.9*	84.7 ± 15.6*	89.3 ± 5.6*	26.1 ± 3.5
Females	20	22.5 ± 8.0	165.9 ± 4.8	68.8 ± 11.9	83.8 ± 4.4	25.0 ± 4.6
Total	38	22.3 ± 7.6	172.5 ± 9.9	76.3 ± 15.8	86.4 ± 5.7	25.5 ± 4.1

* Significant difference between males and females ($p < .05$)

Each subject wore a pedometer on both the right (R) and left (L) hips, but since there was no significant difference between them, the right hip was used for statistical analysis. The correlation between the step counts registered by the pedometers on the R and L hips was 0.81. Table 2 summarizes the steps measured on each hip.

Table 2. Step Counts for Right and Left Hip (mean ± SD)

	n	R hip/30 min	L hip/30 min
Males	18	3133 ± 559	3071 ± 707
Females	20	3249 ± 798	3243 ± 833
Total	38	3191 ± 689	3161 ± 770

Table 3 presents the walking values collected for the 38 subjects tested in the current study. The HR and RPE data reflect that the subjects were engaged in a moderate level of physical activity. The average RPE for the group was approximately 11, which is "fairly light."

Table 3. Walking Data for 30-minutes (mean ± SD)

	n	HR (beats/min)	RPE	Speed (m/min)	Steps (R hip/30 min)	Cadence (steps/min)	Steps/km
Males	18	102 ± 9	10.7 ± 1.2	76.0 ± 13.3	3133 ± 559	104.4 ± 19	1374 ± 238
Females	20	110 ± 12	10.5 ± 1.5	77.5 ± 16.8	3249 ± 798	108.3 ± 27	1397 ± 307
Total	38	106 ± 11	10.6 ± 1.3	76.8 ± 15.1	3191 ± 689	106.4 ± 23	1386 ± 273

No significant difference between males and females ($p < .05$)

Table 4 presents the energy expenditure measured during the walking trials. The males expended significantly more kilocalories than the females when expressed per minute or per kilometer. However, when caloric expenditure was expressed relative to body weight, there were no significant differences between males and females.

Table 4. Energy Expenditure During the 30-Minute Walking Trial (mean ± SD)

	n	kcal/min	kcal/min/kg	kcal/km	kcal/km/kg
Males	18	6.2 ± 1.5*	0.07 ± 0.02	81.6 ± 18.5*	0.96 ± 0.13
Females	20	4.6 ± 0.9	0.07 ± 0.01	59.4 ± 12.9	0.86 ± 0.08
Total	38	5.4 ± 1.5	0.07 ± 0.02	70.3 ± 19.2	0.92 ± 0.12

* Significant difference between males and females ($p < .05$)

In Table 5, data for the 30-minute walking trials were extrapolated to 10,000 steps. For all subjects combined, completing 10,000 steps is projected to require 507 kilocalories, cover 7.2 kilometers, and take 93.9 minutes. There were no significant differences between males and females.

Table 5. Extrapolation of Data from the 30-Minute Walking Trial to 10,000 Steps (mean ± SD)

	n	kcal/10,000steps	km/10,000steps	Time (min/10,000steps)
Males	18	594 ± 195	7.2 ± 1.4	95.8 ± 27.9
Females	20	425 ± 261	7.1 ± 2.4	92.3 ± 57.1
Total	38	507 ± 235	7.2 ± 2.0	93.9 ± 45.2

No significant difference between males and females ($p < .05$)

DISCUSSION

The college-aged males and females in the study expended an estimated average of 507 kcal in 10,000 steps, based on 30-minutes of walking data. Extrapolating the data based on walking speed, it would have taken the subjects approximately 1 hour and 34 minutes or 7.2 km (4.5 miles) to walk the 10,000 steps. The energy expended by the subjects in the current study is slightly higher than those performing level walking on a surface other than a treadmill (11, 22). Ainsworth et al. (11) found an estimated energy expenditure range of 3.0-5.2 kcal/min for both males and females walking at speeds of 53.6 m/min and 80.5 m/min. McArdle and colleagues (22) cite a range of 3.5-4.0 kcal/min at a walking speed of approximately 4.5 km/hr. However, they also noted that moderate physical activity results in an energy expenditure of 5.0-7.4 kcal/min. The participants in the current study met that criterion with an average energy expenditure of 5.4 kcal/min. When converting data from McArdle and colleagues (22) to include body weight, their results yield an energy expenditure expressed as 0.075 kcal/min/kg or as 0.93 kcal/km/kg. Both of these numbers are in close agreement with the current study. Other studies have also related energy expenditure for males and females to body weight. They report the average energy expenditure for males and females to be 4.93 kcal/kg/hr for males and 4.49-5.16 kcal/kg/hr for females (13, 23). However both of those studies looked at walking speeds of 5.47 km/hr and the subjects in the current study walked an average of 4.61 km/hr and had an overall average of 4.22 kcal/kg/hr. The energy expenditures in the current study were slightly lower, which is probably due to the slower walking pace.

There were significant differences between males and females in the current study in the general physical characteristics one would anticipate: height, weight, and leg length. The significant differences between males and females for kilocalories per minute and kilocalories per kilometer are due to the differences in body weight. However, when extrapolating the data to predict energy expenditure in 10,000 steps, there were no differences noted between the males and the females. This lack of difference is likely due to the large variability in step count values among the subjects.

Pedometers have been shown to be relatively accurate, especially in a controlled setting (5-9). Though numerous studies have assessed the energy cost of walking (some examples: 11-14), few have related energy expenditure to step count (10). Hatano (10) determined 10,000 steps per day was equivalent to an expenditure of approximately 300-400 kilocalories per day, depending on walking speed and body size. Hatano studied Japanese males (average height = 170cm and average weight = 60kg). When walking slowly, at a speed of 70 m/min, the subjects expended 336 kcal/10,000 steps; and at a fast walking speed, 85 m/min, they expended 432 kcal/10,000 steps. This differs slightly from the current study, where the range of energy expenditure extrapolated for 10,000 steps was 425-594 kcal. This difference is probably due to the differences between height and weight among the participants, as well as the inclusion of both males and females in the study. Those participating in the current study were an average of 172.5 cm tall and weighed an average of 76.3 kilograms (see Table 1). Both of these values are greater than the Japanese males studied by Hatano.

LeMasurier and colleagues (15) found that 30-minutes of moderate physical activity can be achieved with less than 10,000 steps. In their study, when all minutes of accumulated moderate physical activity were considered, 91% of the >10,000-steps group and 77% of the <10,000-steps group accumulated over 30-minutes of moderate physical activity. They noted that those individuals who accumulated at least 10,000 steps per day were more likely to meet the current physical activity guidelines. In the current study, it would have taken all of the subjects more than 30-minutes to achieve their 10,000 steps.

According to the U.S. Surgeon General's activity guidelines, 30-minutes of moderate physical activity are equivalent to an expenditure of approximately 150 kcal (2). This is supported by the data from the current study, since the subjects averaged an energy expenditure of 5.4 kcal/min when walking at a moderate pace. This equates to 162 kcal over 30-minutes, which is in accordance with the above recommendations.

Tudor-Locke and co-workers (16) noted that in normal daily living, individuals accumulate ≈ 6000-7000 steps per day, and 30-minutes of moderate intensity walking adds ≈ 3000-4000 steps. The current study supports their findings, since the subjects averaged 3191 steps in 30-minutes. Thus, if people were to add 30-minutes of moderate intensity walking to their normal daily activities, they would achieve a daily total of ≈ 9000-11,000 steps per day. For this reason, 10,000 steps per day are considered to be a reasonable goal for healthy adults.

One of the strengths of the current study is that it is the only study that reports energy expenditure per 10,000 steps for both males and females. As noted above, Hatano (10) studied only Japanese males and the other two studies did not report energy expenditure (15, 16). A limitation of the current study is that the results were derived during 30-minutes of consistent stepping on a level treadmill. The data was then extrapolated to estimate energy expenditure for 10,000 steps. It is expected that in daily living, many of the steps recorded would be more varied in velocity and length than that associated with treadmill walking. Therefore, in daily living, the energy expenditure associated with 10,000 steps would be different than that found with treadmill walking. The subjects in the current study were also young college-aged individuals, so the results may not generalize to older or younger populations.

CONCLUSION

The study supports the accumulation of 10,000 steps per day using a pedometer to meet and exceed current activity guidelines. The relationship between energy expenditure and steps taken allows one to view their overall energy balance in a new light. An advantage, as noted by Tudor-Locke et al. (16), is that with step goals, one is focused on behavior, so it therefore applies to individuals of all body sizes. There have been studies that provided an estimate of caloric expenditure while walking. The value of the current study is that it provides an estimate of the caloric expenditure of walking 10,000 steps, as well as an estimate of how long doing so will take in time and distance. Finding that the subjects would expend approximately 507 kcal, cover approximately 7.2 km, and take approximately 94 minutes when accumulating 10,000 steps demonstrates that the recommendation to achieve 10,000 steps per day would exceed the minimum recommendation for physical activity given by the U.S. Surgeon General and the U.S Dietary Recommendations for physical activity. However, these 10,000 steps equate to approximately four and a half miles of walking each day and thus this may not be a realistic goal for some people.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD PROPOSAL

OSU Institutional Review Board (IRB)

Relating Energy Expenditure to Step Count During Level Walking

Application for Approval of the OSU Institutional Review Board (IRB)

For the protection of Human Subjects

1. Significance of the Project

Physical inactivity is a widespread problem in the United States, with 1 in 4 adults leading a sedentary lifestyle. Walking is an activity most individuals naturally do on a daily basis. As a result, a major reason for promoting walking as a mode of physical activity is that it is a relatively simple activity most individuals can perform throughout their entire life.

Pedometers (step counters) have been shown to accurately record one's steps while walking and are increasingly being used as a motivational tool for daily physical activity. While there are numerous studies that have assessed the energy cost of walking, none have related energy expenditure to step count. The primary aim of the proposed study is to relate accumulated steps during level walking to energy expenditure. A secondary aim of the proposed study is to make comparisons between males and females in the energy cost of stepping.

2. Methods and Procedures

The proposed study seeks to determine the relationship between step count and energy expenditure during level walking. The data will be collected at the Health and Human Performance Lab at Oregon State University.

Data collection for each subject will require approximately 1.0 hour. The initial evaluation will include collection of general demographic information, leg length, and a PAR-Q readiness questionnaire. Demographic information includes: age, gender, height, weight, and current exercise habits. Each subject's age, gender, race/ethnicity, and current exercise habits will be completed by the subject themselves, while height and weight measured without shoes will be determined using a wall stadiometer and a scale. The leg length will be determined by the investigator using a spring loaded tape measure. The investigator will measure from the anterior superior iliac spine to the medial malleolus (hip bone to ankle). The PAR-Q will be used to assess an individual's readiness to begin physical activity. Any individual answering yes to one or more questions will be excluded from the study. During the walk test, heart rate, rate of perceived exertion, step count, oxygen consumption, and treadmill speed will be collected.

Heart Rate and Rating of Perceived Exertion

Heart rate will be assessed using a Polaris heart rate monitor. A resting heart rate will serve as a baseline value to allow the investigator to determine the extent of each subject's heart rate increase in response to the exercise. Rating of Perceived Exertion (RPE) is a subjective evaluation of the level of difficulty of the exercise as perceived by each subject. Heart rate and RPE will be assessed at minutes 5, 10, 20, and 30 to allow the investigator to determine the subject's comfort level with the self-selected pace.

Step Count and Oxygen Consumption

Each subject will wear a lightweight, digital pedometer (Yamax Digiwalker) clipped to the subjects' belt or waistband on both the right and left sides. The pedometer will record the total number of steps taken during the 30-minute walk test. The subject's oxygen consumption will be measured continuously throughout the 30-minute walk test using a Sensormedics 2900 metabolic cart. Each subject will wear a nose clip and breathe through a mouthpiece. Energy expenditure will be calculated based on the oxygen consumption measurements, and then related to step count.

Walking Speed

After completion of the informed consent and preliminary data collection, each subject will be oriented to walking on the treadmill. Each subject will self-select their own walking speed and this will be determined during a 5 minute warm-up period. The investigator will adjust the speed, either up or down, according to the request of the subject. The subject will determine the overall speed to be used during the testing procedures. However, each subject will be instructed to walk purposefully for 30-minutes, so that they are walking at a moderate pace, but one that is not too strenuous for them. The speed of the treadmill will be compared to a digital tachometer and confirmed during each walk test. The total distance walked will be calculated based on each subject's walking speed during the 30-minute duration of the walk test.

Data Analysis

The primary aim of the proposed study is descriptive, in that it will relate energy expenditure to walking speed and step count. The secondary aim of the proposed study is to determine gender differences in self-selected walking speed, step count, stride frequency, and stride length. A t-test will be used to test for these gender differences.

3. Benefits and Risks

Benefits

Subjects participating in the study will receive information regarding their energy expenditure during level walking. This will include information for total energy expended during the 30-minute walk test and the energy expended per step.

Risks

Minor discomfort may be associated with the measurement of oxygen consumption from wearing the nose clip and mouthpiece for the 30-minute test. The use of a padded nose clip and the limited vertical movement of the headgear that occurs while walking on the treadmill will help to keep subject discomfort at a minimum.

4. Subject Population

Approximately 30 volunteers will be recruited from Oregon State University through class announcements, where fliers containing the necessary information will be available for potential subjects to pick up along with the same fliers being posted around the university. Both males and females will be recruited for participation in the proposed study since a secondary aim of the study is to make gender comparisons. There are no age restrictions for participation in the proposed study, other than subjects must be at least eighteen years old.

5. Informed Consent Document

A copy of the informed consent for the proposed study is attached.

6. Methods by which the informed consent will be obtained

Participants will be asked to read and sign the informed consent prior to their participation in the proposed study. Participants will be informed of their right to withdraw from the study at any time without prejudice. Any questions regarding the proposed study, testing procedures, or any other subject concerns, will be answered by the principal investigator.

7. Method by which subject confidentiality will be maintained

Subject information will only be available to the researcher and the research staff of the proposed study. The subjects' identity will remain anonymous by the use of identification numbers instead of names in the data entry analysis. A data file will be created to link subjects' identities (names, email addresses, and phone numbers) with the data in order to contact and send participants their test results. This file will only be accessible to the researchers and will not be kept past the project duration.

8. Questionnaires, surveys, and testing instruments

The PAR-Q Readiness Questionnaire along with the data sheet containing the collection of personal information is attached.

9. Other approvals

The proposed study does not require the approval of any additional agencies or institutions.

Department of Exercise and Sport Science

OREGON STATE UNIVERSITY

Informed Consent Form

A) Title Of The Research Project

Relating Energy Expenditure to Step Count During Level Walking

B) Investigators

Anthony Wilcox, Ph.D. (principal investigator)
Kari L. Birdsley, B.S. (co-investigator)

C) Purpose Of The Research Project

The primary aim of the proposed study is to relate energy expenditure during 30-minutes of level walking to the number of steps taken and how many calories a person burns with each step. A secondary aim of the proposed study is to make comparisons between males and females for the energy cost of walking.

D) Procedures

I understand that as a participant in this study the following things will happen:

What participants will do during the study?

As a participant in this study, I will report to the Human Performance Lab in the Women's Building at Oregon State University for a test session that will last approximately one hour. I will report to the test site dressed in T-shirt, shorts, and wearing a comfortable pair of walking shoes.

I will complete a short questionnaire regarding my age (minimum of 18 years required for participation), gender, race/ethnicity, and exercise habits, as well as another short questionnaire concerning my readiness for physical activity. I understand that I must pass the readiness questionnaire (be healthy) in order to participate in this study. My height, weight, and my leg length (the distance from my hip bone to my ankle) will be measured. During the walk test:

1) I will self-select my own walking speed during a 5-minute warm-up on the treadmill. I will be asked to walk at a purposeful pace, but not a "power walk" pace. I will select a pace I can manage comfortably for 30-minutes. Once selected, the pace will be held constant during the remainder of the warm-up and during the 30-minute trial.

2) My heart rate will be assessed using a heart rate monitor at times 0, 5, 10, 20, and 30-minutes. The heart rate monitor is an elastic strap worn around my chest and under my shirt.
3) I will report my Rating of Perceived Exertion (RPE) at times 5, 10, 20, and 30-minutes.
4) I will wear a lightweight pedometer (step counter) on both my right and left hips that will record the total number of steps taken during the 30-minute walk test.
5) I will wear a padded nose clip and mouthpiece for the duration of the walk test. This mouthpiece will be connected to a gas analyzer and measure the amount of oxygen consumed during the 30 minute walk test.

E) Foreseeable Risks Or Discomforts

The only potential risks or discomforts to me as a subject in this research project are the possibility of slight discomfort from wearing the nose clip and mouthpiece for the duration of the 30-minute walk test. Since I selected the walking pace, I should be able to complete the 30-minutes of walking without difficulty.

F) Benefits To Be Expected From The Research

I will receive information regarding the total energy expenditure during level walking and the energy expended per step.

G) Confidentiality

Any information obtained from me will be kept confidential. A code number will be used to identify any test results or other information that I provide to the investigator. The only persons who will have access to this information will be the investigators, and no names will be used in any analysis, data summaries, or publications that result from this project.

H) Compensation For Injury

I understand that the University does not provide a research subject with compensation or medical treatment in the event that the subject is injured as a result of participation in the research project. I can stop the test at any time if I become tired or if I find it difficult.

I) Voluntary Participation

I understand that my participation in this study is completely voluntary and that I may either refuse to participate or withdraw from the study at any time without penalty or prejudice. If I become tired or if I do not wish to continue walking on the treadmill for any reason, I can indicate this to the investigators, and the test will be stopped.

J) Questions Regarding The Study

I understand that any questions I have about this research study, specific testing procedures or any other concerns should be directed to:
Anthony Wilcox, Ph.D. (principal investigator), 214 Langton Hall, Oregon State University, Corvallis, OR 97331 (541)737-2463 or Kari L. Birdsley B.S. (co-investigator) 121-G Langton Hall, Oregon State University, Corvallis, OR 97331 (541)737-6793.

If I have questions about my rights as a research subject, I should contact the IRB Coordinator, OSU Research Office, (541)737-8008.

K) Understanding And Consent

My signature below indicates that I have read and that I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form

____
Name of Subject

____
Signature of subject   Date Signed

____
Subject's Present Address

____
Subject's Present Phone Number   Subject's Present Email Address

____
Signature of Principal Investigator   Date Signed

Data Collection Sheet for Personal Information

Subject's Identification Number:______________________________

Age:________ **Gender (please circle):** Male Female

Race/Ethnicity (please check all that apply):

___ White, European American, Non-Hispanic
___ Asian or Asian American
___ Black, African American, Non-Hispanic
___ Middle Eastern or Middle-Eastern American
___ Pacific Islander
___ Hispanic or Latino American
___ American Indian or Alaskan Native
___ If none of the above choices apply to you, please use your own description:

____

___ Decline to respond

Height:___________m **Weight:**__________kg

Leg length:__________cm

Current Exercise Habits:

Number of days per week:________days

Length of time per exercise session:__________minutes

Intensity (please check the level most accurately describing each exercise session):

___ Low intensity
___ Moderate intensity
___ High Intensity

List the types of exercise performed (e.g. running, cycling, aerobics class, weight lifting, etc.):

____

____

Laboratory 2.1

PAR-Q: The Physical Activity Readiness Questionnaire

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	*1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?*
☐	☐	*2. Do you feel pain in your chest when you do physical activity?*
☐	☐	*3. In the past month, have you had chest pain when you were not doing physical activity?*
☐	☐	*4. Do you lose your balance because of dizziness, or do you ever lose consciousness?*
☐	☐	*5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?*
☐	☐	*6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?*
☐	☐	*7. Do you know of any other reason you should not do physical activity?*

IF YOU ANSWERED

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about PAR-Q and which questions you answered YES.

You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those that are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his or her advice.

Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active. Begin slowly and build up gradually; this is the safest and easiest way to go.
- take part in a fitness appraisal. This is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

If you are not feeling well because of a temporary illness such as a cold or fever, wait until you feel better. If you may be pregnant, talk to your doctor before you start becoming more active.

Please note: If your health changes so that you answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change you physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

Source: From the Canadian Society for Exercise Physiology, 1994.

You are encouraged to copy the PAR-Q but only if you use the entire form.

APPENDIX B

LITERATURE REVIEW

The relationship between physical inactivity and cardiovascular disease (CVD) has far reaching public health implications. The hundreds of thousands of deaths each year and the billions of dollars spent each year treating individuals with CVD make this not only a nationwide concern but a worldwide concern as well. Coronary heart disease (CHD) is currently projected to be the leading cause of disability in the world in the 21st century (1). According to the American College of Sports Medicine, the major risk factors associated with CVD are: age, family history, current cigarette smoking, hypertension, hypercholesterolemia, diabetes mellitus, and sedentary lifestyle/physical inactivity (2). A positive relationship has also been observed and documented between physical inactivity and hypertension, hypercholesterolemia, and diabetes mellitus.

In 1996, a U.S. Surgeon General's Report was released and it proposed a new set of activity guidelines. The former guidelines prescribed a minimum of thirty minutes of aerobic exercise at least three days a week. These guidelines proposed a fairly high intensity exercise routine at 60-80% of maximal heart rate. These guidelines were designed to achieve aerobic fitness. Unfortunately, a large percentage of the American population was not meeting these guidelines. According to this report, more than 60% of American adults are not regularly active, and 25% of the adult population is not active at all (1). However, as more evidence accumulated, health benefits were found to be achieved at lower levels of intensity. The Healthy People 2000 objectives also focused on trying to increase Americans' physical activity levels by the year 2000. Its desired goal is to increase to at least 30 percent of people aged 6 and older who engage regularly, preferably daily, in light to moderate physical activity for at least 30-minutes, and to reduce to no more than 15% the proportion of people aged 6 and older who engage in no leisure-time physical activity (3). The new activity guideline proposes an accumulation of thirty minutes of moderate intensity exercise on most, if not all, days of the week (1).

Physical activity and physical fitness have both been used to determine associations with health and disease. Typically physical fitness is estimated using aerobic capacity; whereas, physical activity is assessed using self-report measures (4). The National Institute of Health (NIH) (1996) defines physical activity as "'bodily movement produced by skeletal muscles that requires energy expenditure' and produces overall health benefits." Exercise is a subset of physical activity and is defined as "a planned, structured, and repetitive body movement done to improve or maintain one or more components of physical fitness" (5). The 1996, U.S. Surgeon General's Report defines physical fitness and health in the following manner. Physical fitness is "the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies." Health is defined as "A human condition with physical, social, and psychological dimensions, each characterized on a continuum with positive and negative poles. Positive health is associated with a capacity to enjoy life and to withstand challenges; it is not merely the absence of disease. An association of negative health is morbidity and in the extreme, with premature mortality" (1).

In the past, exercise scientists recommended that individuals exercise primarily to maintain or develop cardiorespiratory fitness. It was assumed exercise training responses were synonymous with health benefits. However, current research findings suggest health benefits are not necessarily determined by improvements in aerobic capacity. The exercise science community has experienced a shift in their paradigm concerning physical activity recommendations. The over arching goal of the present guidelines is to increase the amount of daily physical activity Americans engage in as a means of improving their overall health.

The traditional, structured approach involves specific recommendations regarding type, frequency, intensity, and duration of the activities. However, the current recommendations adopt a lifestyle approach to increasing physical activity. In this case, sedentary individuals can increase their physical activity in a variety of ways.

Haskell generated a dose-response curve based on studies found in the literature up to that point in time. In his review of the literature, he notes the greatest health benefits were observed when sedentary individuals began a regular program of moderate intensity, endurance-type activities. This means that for any given increase in the amount of activity, the magnitude of the health benefit is inversely proportional to the baseline status (6). Since 25% of the American population is sedentary, this has major health implications. A small increase in activity for these sedentary individuals can have major health benefits for them.

All-Cause Mortality

Mortality refers to the proportion of deaths in a given population. When referring to all-cause mortality, one is not concerned with the actual cause of death but merely the fact that the individual is deceased. This is different from morbidity rates, which look at the relative incidence of a disease. These are both ways in which exercise scientists view the relationship between certain risk factors for a disease and its relationship to occurrence or death because of it.

The Harvard Alumni Study demonstrated an inverse relationship between all-cause mortality and increment of reported physical activity. The risk of death in males with an activity index of less than 500 kcal was more than twice that associated with those in the most active group, 3,500 kcal/week (7). Leon et al. measured leisure time physical activity (LTPA) and reported 38% fewer fatal CHD events and sudden deaths among those in the middle tertile as compared to those in the lowest tertile of LTPA (8). A study at the Lipid Research Clinic observed 4,276 white males aged 30-69 years. Researchers found, after adjusting for age and other cardiovascular risk factors, mortality from CVD was 8.5 times higher in the quartile with the lowest level of fitness compared to those in the highest fit quartile (9). Blair and colleagues followed 9,777 males and assessed them for physical fitness based on maximal exercise testing. Individuals who were initially in the bottom 20% (low fitness status) and improved to at least moderately fit had a 44% lower all-cause death rate and a 52% lower CVD death rate than males who remained unfit (10). Weller and Corey also noted the most important finding from their study was the consistent inverse relationship between physical activity and mortality in females 35-65 years of age. These authors felt this inverse relationship was due primarily to energy expended in non-leisure activity, since the females in their study expended considerably more energy in non-leisure activity (mean expenditure = 7.0 kilocalories per kilogram body weight per day) than in leisure-time activities (mean expenditure = 1.2 kilocalories per kilogram body weight per day). On average, 82% of the total activity in females was represented in non-leisure energy expenditure. They addressed household chores and occupational activity, as well as non-leisure activity which provided a broader assessment of total activity and one which they hoped would not lead to such an underestimation of the relationship between physical activity and mortality. They also noted that when calculating energy expenditure using only leisure-time physical activity, it led to an underestimation for those females whose activity was primarily comprised of household chores (11). The Villeneuve et al. study was based on the nineteen most frequently reported leisure-time physical activities. In that study, no inverse relationship between physical activity and mortality was observed (12). Evidence from the Weller and Corey study suggests this lack of inverse relationship between physical activity and mortality was due to the exclusion of non-leisure activities. In 1995, the Centers for Disease Control and Prevention and the American College of Sports Medicine noted physical activity reduces the risk of CHD through a variety of physiological and metabolic mechanisms. These include: the potential to increase the level of high-density lipoproteins cholesterol, reducing serum triglyceride levels, reducing blood pressure, enhancing fibrinolysis and altering platelet function, enhancing glucose tolerance and insulin sensitivity, and reducing the sensitivity of the myocardium to the effects of catecholamines (13).

Measurement of Energy Expenditure

Since physical activity is associated with numerous health benefits, accurate assessment of one's level of activity becomes important. Energy expenditure is one way of measuring or determining an individual's level of activity. Total energy expenditure refers to the total number of kilocalories an individual expends or burns in a twenty-four hour period. There are two major methods used to measure energy expenditure: direct and indirect calorimetry. Direct calorimetry is the measurement of heat emission. It uses the gradient-layer principal to measure the heat flux out of the chamber. The heat flux is driven by the temperature difference between objects inside the calorimeter and the chamber wall (14). It requires the individual to remain in a whole-room calorimeter for the duration of the study. Direct calorimetry is highly accurate, yet its use is limited. The human calorimeter is relatively expensive to build and maintain and is not applicable to assessing energy expenditure in most sport, recreational, and occupational activities (15). Indirect calorimetry is the measurement of respiratory gas exchange, oxygen consumption and carbon dioxide production, which is then used to calculate energy expenditure (14). Closed-circuit and open-circuit spirometry are the two major applications of indirect calorimetry. Closed-circuit spirometry is used in hospital and other lab settings to estimate resting energy expenditure but is rarely used during exercise. As a result, open-circuit spirometry is the most widely used procedure to measure oxygen uptake during exercise. Energy expenditure is then indirectly determined from the measurements of oxygen uptake (15).

Doubly labeled water is another method used to measure energy expenditure and was developed by Lifson and McClintock during the 1950's. This technique measures energy expenditure from the disappearance rates of non-radioactive oxygen (^{18}O) and hydrogen ($^{2}H_2$). These are both naturally occurring, stable isotopes, which makes this a very safe technique to use. This method is based on the assumption that oxygen (^{18}O and ^{16}O) in expired carbon dioxide and in the total body water pool are in isotopic equilibrium (14). According to Lifson, the ^{18}O isotope is eliminated from the water pool as water and carbon dioxide, whereas ^{2}H is eliminated only as water. The difference in the elimination rates of the ^{18}O and ^{2}H is related to the carbon dioxide production rate, and this, in turn, has been related to energy expenditure (16).

Direct and indirect calorimetry and doubly labeled water have all been found to be reliable techniques of assessing human energy expenditure (14, 15). The above techniques all require highly specialized equipment and training on the part of the technician. Equations have been derived from these methods that predict one's total energy expenditure. The use of these equations has extremely practical implications in the field. Physical activity questionnaires, blood pressure, pedometers, accelerometers, and timed walking tests, along with demographic information like age and gender, are used in these equations to estimate one's energy expenditure.

Total energy expenditure as previously mentioned sums the total number of kilocalories an individual burns in a twenty-four hour period. It does not distinguish which activities are contributing to this expenditure. Three main components of energy expenditure are: basal metabolic rate (BMR), thermic effect of feeding, and physical activity (15). The BMR is the minimal level of energy required to sustain the body's vital functions in the waking state. It is determined indirectly by measuring oxygen uptake under fairly stringent conditions. The resting metabolic rate (RMR) is measured under less strict conditions, three to four hours after a light meal and without prior physical activity. The RMR is typically only slightly higher than the BMR (15). With the shift in activity guidelines to a more lifestyle approach, physical activity can have an effect on one's overall daily energy expenditure, but may be most pronounced among sedentary individuals. Of the three main components represented in one's daily energy expenditure, physical activity is the area over which we can have the greatest influence. It has been shown that 22% of Americans are inactive and 34% irregularly engage in leisure time activity (17). This indicates that the majority of their total daily energy expenditure is represented by the thermic effect of food and BMR. This lack of the energy expenditure from physical activity is believed to be responsible, at least in part, to the increased prevalence of overweight individuals in the US.

The Morris et al. study of double-decker bus drivers and conductors measured occupational physical activity and its potential cardioprotective implications (18). They reported that the bus drivers who expended small amounts of energy during their shift, occupationally sedentary individuals, were 1.8 times more likely to suffer a coronary heart disease event as compared to their occupationally active conductors, who spent large amounts of energy walking and climbing stairs as they collected tickets from their passengers. Paffenbarger and colleagues' San Francisco Bay area longshoremen study helps to further promote the idea that occupational physical activity can increase one's total daily energy expenditure. This increase in total daily energy expenditure has been previously shown to have health benefits. They reported the longshoremen expending 2.4 to 4.0 kilocalories per minute on the job were 1.8 times more likely to suffer a fatal CHD event as compared to the longshoremen expending 5.2 to 7.5 kilocalories per minute on the job (19). It appears as if the amount of energy expended is more important than one's choice of activity, either a fitness activity or a non-leisure time physical activity. The above studies focused on occupational energy expenditure, while Duncan and co-workers examined the effects of various exercise intensities and duration of walking on maximal oxygen uptake and serum high-density lipoprotein cholesterol (HDL-C). In this study, the walking trials were roughly isocaloric. This means that both groups of walkers, "the strollers" and "the aerobic walkers" used approximately the same number of kilocalories. Those females who walked at a lower intensity, "the strollers," walked for a greater duration than those females who walked at a higher intensity, "the aerobic walkers." An increase in one's walking intensity was associated with an increase in aerobic capacity. However, health benefits (increased serum HDL-C levels) were similar regardless of the walking intensity (20). Similar findings were reported by Hagberg and colleagues when they compared walking versus running. Again, the activities were isocaloric and the health benefits between the two groups were similar (21).

The choice of activity used as a means for expending energy seems irrelevant to obtain health benefits. If one's goal is improved aerobic capacity, then the choice of activity becomes very important. The overall effect of expending energy is what appears to be most important. This means the source of energy expenditure can come from a leisure-time or non-leisure time physical activity. This is potentially why Weller and Corey noted an underestimation of energy expenditure when only monitoring leisure-time physical activity. The majority of females in their study spent their time engaged in non-leisure time physical activities, like household chores (11). The new exercise guidelines include non-leisure physical activities, like household chores, along with the more traditional leisure-time activities.

Both cross-sectional and longitudinal studies have shown that fat-free mass (FFM) decreases with age (22, 23). According to Keys and colleagues, the BMR is estimated to decrease about 1-2% per decade in adult life (24). However, this assumes body weight remains constant, and other epidemiological evidence has shown the population tends to gain weight up until about 65 years of age (25, 26). It has been shown that once activity and body composition have been compensated for; there is not a linear age effect on energy expenditure (27). The changes in energy expenditure observed with aging are influenced primarily by changes in one's body composition and level of activity.

Relationship between Physical Activity and Energy Expenditure

Walking is an activity most individuals perform each day. The amount or extent to which one walks depends on an individual's occupation and the lifestyle choices one makes. For many, walking is merely a part of their job, while for others; it is an activity that they purposefully choose to do. An easy, cost-effective, and accurate measure of energy expenditure could have great potential when assessing the energy expenditure of individuals in epidemiological studies.

In 1957, Booyens and Keatinge investigated the energy expenditure of males and females during walking. They noted that walking at $5.47 km \bullet hr^{-1}$ females expended significantly less energy than males per unit body weight, 4.49 kilocalories per kilogram body weight per hour for the females and 4.93 kilocalories per kilogram body weight per hour for the males. This same difference in energy expenditure between genders was observed at $6.44 km \bullet hr^{-1}$ as well. The females expended an average of 5.12 kilocalories per kilogram body weight per hour while the males averaged 5.86 kilocalories per kilogram body weight per hour, or a difference of 0.74 kilocalories per kilogram body weight per hour. The females also took significantly shorter and more frequent strides per minute than the males in their study. The females took an average of 126.43 strides/minute with an average stride length of 72.20cm while walking at $5.47 km \bullet hr^{-1}$. The males, on the other hand, took an average of 106.70 strides/minute with an average stride length of 85.61cm. An even greater difference was noted when the walking speed was increased to $6.44 km \bullet hr^{-1}$. The females walked with an average of 141.06 strides/minute while the males averaged 114.93 strides/minute and their corresponding stride lengths were 76.20cm and 93.34cm respectively. These authors found the overall difference in energy expenditure between the males and females increased with speed (28).

The above authors believe the lower energy expenditure by the females was related to their shorter stride length. Booyens and Keatinge hypothesized that the females spent a smaller amount of work lifting their bodies vertically, which would result in a decrease in energy expenditure with each step. The reasoning used to support this difference in vertical movement is based on the slightly different position of the acetabular fossae in females versus the males. In females, the difference in position of the acetabular fossae would result in slightly shorter iliofemoral ligaments. Potentially, these shorter iliofemoral ligaments could restrict extension of the hip and result in a shorter stride length for the females (28). Mahadeva and colleagues observed similar results, and reported both the length and frequency of the stride increase proportionally with increased speed of walking for both males and females (29). However at slower speeds, such as 3mph or less, the difference in stride length and frequency was so small there was not a significant difference in energy expenditure between the males and females (28, 29).

Relationship of Stride Length and Frequency and Energy Expenditure

Several authors have found that the preferred walking gait for an individual resulted in minimal metabolic costs for that person (30-35). The optimal walking pace for an individual result in the least amount of energy being expended per distance covered. However, stride frequency above and below one's optimal stride frequency results in increased energy expenditure, possibly due to an inefficiency of the gait itself. (31). McArdle, Katch, and Katch (15) also noted this same phenomenon, where the relationship between walking speed and oxygen uptake is approximately linear between speeds of 3.0 and 5.0 km per hour. As the speed increases, walking economy decreases and the oxygen consumption increases disproportionately upward.

Holt et al. observed that the combination of low frequency/long stride length produced significantly higher metabolic costs than the equivalent high frequency/short stride length (31). Minetti and colleagues also studied stride length and frequency in relation to energy expenditure and power. They found humans choose, at any given walking speed, the stride length and frequency that minimizes their oxygen consumption (32). This minimal use of oxygen is related to the most efficient stride possible for the walking speed, therefore conserving as much energy as possible. In other words, humans select a gait that results in minimal energy expenditure for any given walking speed. There is an optimal stride frequency that individuals prefer to use because it results in the least amount of energy spent, but an individual has the ability to adapt to any walking speed. Bunc and Dlouha provided a possible hypothesis as to why this might occur. At higher frequencies, subjects are better able to take advantage of the elastic return in muscle and connective tissue (30). Asmussen and Bonde-Peterson have proposed that energy can be stored elastically during a continuous motion, whereas stored energy is lost during brief periods of relaxation. They conducted a study that helps to support this concept. These authors reported a 25% lower energy cost in those subjects who moved continuously through a stand-sit-stand task without any pause between the two motions. This was compared to those who had a brief pause, allowing the muscles to relax between each phase of the task (35). It is also believed that this storage of elastic energy is a function of the rate of pre-stretch of the muscle. Cavagna and colleagues defined the elastic storage requirement as a shortening preceded by an active pre-stretch. As a result of this pre-stretch, the conventional tension-length curve is modified (36).

Metabolic Calculations of Energy Expenditure

As previously mentioned, energy expenditure is related to oxygen consumption and the use of indirect calorimetry allows one to calculate the relationship. Balogun et al. found patients in a clinical setting are not nearly as concerned with how much oxygen they consumed during the exercise as they are with their energy output or energy expenditure (37). These clinical applications are just one more reason why finding accurate prediction equations for energy expenditure at various walking speeds are so important. The authors in the above study proposed their own prediction equation and cross-validated the existing ACSM and Bubb et al. equations currently in use with their results. These authors found good agreement with the prediction equations for the measured values of oxygen consumption (VO_2) at speeds between $3.24 km \bullet hr^{-1}$ and $6.42 km \bullet hr^{-1}$. The ACSM formula tended to underestimate VO_2 by 30.1% at the fast walking speed ($7.8 km \bullet hr^{-1}$). On the other hand, the Bubb et al. formula tended to overestimate VO_2 by 15.4% at the slow walking speed ($3.24 km \bullet hr^{-1}$). The equation used by Bubb et al. is as follows:

$$EE\ (kcal/min) = 6.4 - 0.1076\ X\ (m/min) + 0.00093X^2$$

They also noted this equation is limited to subjects under the same conditions as those in their study. This study looked at individuals walking on a flat or horizontal surface (37).

Studies over the decades have been performed to estimate exactly what humans expend while performing various activities. These studies have become the basis for the charts seen in books or at health clubs which relate an activity to the amount of energy expended while performing that activity. Since this paper focuses on energy expenditure and walking, only those studies relating to walking specifically will be addressed.

A MET is a metabolic equivalent used to represent the metabolic cost of an activity. It is defined as a multiple of the resting metabolic rate. The average man has a resting oxygen uptake of about 250mL per minute, while it is only about 200mL per minute for the average woman. A MET is usually expressed in terms of oxygen uptake per unit body mass to help account for the variations in body size. One MET is equivalent to approximately $3.6 mL \bullet kg^{-1} \bullet min^{-1}$ (24). The ACSM Guidelines for Exercise Testing and Prescription define 1 MET as equivalent to $3.5 mL \bullet kg^{-1} \bullet min^{-1}$ (2). A five level classification of physical activity has been developed based on exercise intensity in terms of liters of oxygen consumed per minute, where 5 kilocalories of energy are expended with each liter of oxygen consumed. This classification system of exercise intensity has been generated based on the weights of an average man and woman. Those weights are a 65-kg man and a 55-kg woman (15).

Ainsworth and colleagues identified and classified the energy costs of various human physical activities (38). In their compendium, they covered a wide variety of activities in which an individual might engage. They classified walking into two major categories: walking associated with one's occupation and walking as a general activity. For each of these main categories, there were numerous subcategories depending on what took place while walking; for example, speed, carrying of a load, uphill, downhill, flat surface, and rough terrain are just a few of the conditions addressed. Occupational walking averaged 4.9 METS, and walking in general averaged 5.4 METS. One must note these values represent walking uphill/downhill, upstairs/downstairs, on level ground, on varying types of surfaces, and carrying loads of different weights while walking in these different conditions. However, if one was to focus strictly at walking on a level surface without carrying a load at speeds ranging from less than 2.0 mph to 4.5 mph, the corresponding energy expenditure values are 2.0 to 4.5 METS. This is less than the average expended for occupational walking, but again it is due to the different conditions associated with each average (38).

When looking at the average MET values from the article by Ainsworth et al., walking in general averaged 5.4 METS as mentioned above. This value would classify the activity as very hard for females, while only being moderate for males according to McArdle, Katch, and Katch (15). The MET value accounts for body mass and so body size does not affect the MET value. However, as previously mentioned, females expend less energy than males at the same walking pace. Therefore, in order for a woman to achieve the same MET level as a man, she would have to correspondingly work harder (walk at a faster pace) in order to expend an equivalent amount of energy in the same amount of time as her male counterpart.

Assessment of Energy Expenditure

Questionnaires and interviews provide investigators or researchers with subjective measures of physical activity levels, but there is also a need for easy, cost-effective, and reliable objective measures as well. In 1992, Gretebeck and Montoye addressed the issue of comparing objective measures of physical activity. These authors compared pedometers, accelerometers, heart rate estimates, and daily caloric intake. The subjects in this study were observed for seven continuous days. This allowed the researchers to determine if the weekends were significantly different from the weekdays. These authors found that indeed Saturday and Sunday were significantly different from the remainder of the week, requiring measurements to be analyzed in two groups, weekdays and weekend days. They experienced a low reliability with the pedometer and only a moderately high correlation with the accelerometer (39). However, the pedometer used in their study was a mechanical one and the newer electrical pedometers have been found to be more reliable and accurate (40). As anticipated, males who were more active during the week tended to be more active on the weekends. Gretebeck and Montoye determined that a minimum of 5-6 days of recordings are needed to accurately estimate habitual physical activity. However, they also noted caloric expenditure could be estimated with fewer observations. In 1992 when this article was published, physical activity was based on traditional exercise activities and did not embrace the current broader, lifestyle approach. Non-leisure physical activity was not included in one's measure of habitual physical activity. However, when non-leisure activities were incorporated as a portion of one's total caloric expenditure they noted fewer observations were needed to estimate caloric expenditure. They recommended scores be recorded in METs or kcal$\bullet$kg^{-1}body weight$^{-1}\bullet$d^{-1}

because it more closely represents physical activity by taking into account body size (39).

A pedometer is a mechanical or electrical motion sensor that records acceleration and deceleration of movement in one direction. When an individual walks, the impact of the foot striking against the ground produces an impulse that is transmitted to the pedometer. A pendulum in the pedometer is displaced a certain distance based on the stride length selected (41). Depending on the type of pedometer selected, the display will either indicate the distance covered or strides taken (40). Washburn and colleagues addressed the issue of the accuracy of pedometers, since up to that point, little was known about their accuracy and they were growing in popularity. They found when the subjects walked at 2 mph, the pedometer tended to under-record the mile distance covered by about 22%. However, they also noted there appeared to be a lack of quality control by the manufacturer because the same brand pedometer was used in each trial and yet one pedometer consistently provided more accurate results that the other two (42). It should also be noted that the brand the authors selected was not mentioned in the study and again mechanical pedometers were selected for use in their study. The authors came up with three major observations from their study. (1) Pedometers perform very poorly at slow walking speeds. (2) Pedometers worn on the waist may provide more reliable measurements that those worn on the ankle. (3) A correction factor must be applied to observe pedometer readings. The correction factor should be individually applied to each pedometer for each individual user based on the appropriate speed and conditions under which it was used (42).

Questionnaires have long been used to assess one's physical activity levels. Sequeira and colleagues noted similar results to Gretebeck et al. when they observed those males who were more active during the week tended to be more active on the weekends as well. They also noted questionnaires have certain inherent limitations in their use. For example, the survey used in their study, the World Health Organization Monitoring Trends and Determinants in Cardiovascular Disease (MONICA), was lacking detail in describing physical activity. The authors felt there probably was less bias when using the objective measure of the pedometer as compared to the self-administered subjective questionnaire. Their summarizing comments supported the use of the pedometer as an objective measure of physical activity in certain situations where a questionnaire is potentially limited in its use (41). There is always the potential for over- and under-estimation of physical activity among the study population. In addition, the majority of self-report surveys may not be accurate across populations and developing a questionnaire adapted to the general population would be difficult. Especially since, the available information for the reliability and validity of these questionnaires is predominantly based on white, middle-aged males.

In 1977, Gayle et al. noted stride length did not appear to affect the pedometer readings. It was more the individual differences in impact force that accounted for the individual differences observed in distance recorded by the pedometer. They also observed that while at a constant speed and on level terrain, the step•min^{-1} counts were usually identical and never varied more than three steps for any individual. However, they pointed out this was under highly controlled laboratory situations and further research is needed on more normal walking surfaces and conditions (43).

Bassett and colleagues assessed the accuracy of five different pedometers on different walking surfaces and at different speeds (40). The pedometers used in their study were electronic pedometers and worked on the same principle as their predecessors, the mechanical pedometers. A horizontal, spring-suspended lever arm moves up and down with vertical accelerations at the hip. With each step taken, the lever arm makes an electrical contact and one event is recorded. Each subject walked on a level sidewalk along a predetermined path of a known distance and the distance recorded on the pedometers was compared to the actual distance walked. The Yamax DW-500 pedometers were the most accurate at recording the distance walked in their study. The authors observed the walking surface, the cement sidewalk (part 1 of the study), as compared to a rubberized outdoor track, did not significantly affect the distance recorded. Again the Yamax showed the closest agreement between two different surfaces, the track and the sidewalk. Part 3 of this study assessed the effect of walking speed on pedometer accuracy. In this instance, each subject walked on a treadmill at five different speeds while the researcher used a hand-tally counter to measure the actual number of steps taken by the subject at each speed. This allowed the researcher to determine the effect of speed on the accuracy of steps recorded by each pedometer. At slow-to-moderate speeds of 3.24-4.8km•hr^{-1} (2.0-3.0 mph), the Yamax was the most accurate. As speed increased to 6.42km•hr^{-1} (4.0 mph), the accuracy of the Eddie Bauer and Pacer pedometers improved and was finally in much better agreement with the Yamax. In this study the Yamax was the most accurate at recording the number of steps taken. The Yamax scored well with an average difference in distance between the two pedometers (one on right hip and one on left hip) of only 0.05km. This was only a 1% difference. The authors in this study concluded the Yamax pedometer was the most accurate brand. In their article they stated: "Electronic pedometers could be used as a criterion measure of 'distance walked' to validate questions about walking on physical activity surveys (40)." It appears as if the newer electronic pedometers have a greater degree of accuracy than the older-style mechanical pedometers. This would allow them to be potentially useful in epidemiological studies regarding the physical activity of free-living individuals.

In the above study, the authors knew the distance walked and observed either the number of steps counted or the distance recorded on the pedometer itself. When distance was recorded, the pedometers had been preprogrammed according to the manufacturer's guidelines. Generally, this included the individual's average stride length as calculated over a fixed distance.

Edelman and Smits believed pedometers could be useful in quantitatively measuring one's activity level because they are relatively inexpensive and easy to use. They felt both quantitative and qualitative measures of activity level are essential to obtaining as accurate a measurement as possible. Each has its own strengths and limitations, so no singular method may be sufficient to measure gross activity level. The pedometer, in combination with a qualitative tool, like a diary, could be useful in researching the relationships between physical activity and obesity or other health-related behaviors (44).

In Japan the use of the pedometer is not only practical but is also widely accepted. The manpo-kei is the nickname they use for the pedometer or step-meter. When translated it literally means "10,000 steps meter." They believe walking this many steps a day is a good idea and should be an individual's target amount of daily exercise. This would result in a daily caloric expenditure of 336 kilocalories to 432 kilocalories, or between 3.2 – 5.4 kilocalories per minute, depending on the walking speed (45). Morris and colleagues demonstrated a cardioprotective effect with expenditures of this magnitude (18). If one were to focus on weekly totals, 10,000 steps per day would generate an expenditure of between 1600-3000 kilocalories per week. Paffenbarger identified health benefits with expenditures of ≥2000 kilocalories per week in his Harvard Alumni study (7). For example, walking with a step rate of 100 steps/minute with a stride length of 70cm (0.7m), the individual would be walking at a pace of 70m/min (45). Therefore, 10,000 steps would equate to 7,000 meters or 7 kilometers or 4.4 miles.

$$\frac{100 \text{ steps}}{\text{min}} \times \frac{0.7\text{m}}{\text{step}} = \frac{70\text{m}}{\text{min}}$$

$$10{,}000 \text{ steps} \times \frac{0.7\text{m}}{\text{step}} = 7{,}000\text{m}$$

(Conversion between units J 7,000m = 7km = 4.4miles)

According to Hatano, a middle size Japanese man walking at a rate of 70m/min would result in an expenditure of 3.2 kilocalories per minute or 30steps/kcal. Therefore, in 10,000 steps, the individual would expend approximately 336 kilocalories.

$$\frac{1 \text{ kcal}}{30 \text{ steps}} \times 10{,}000 \text{ steps} \approx 336\text{kcal}$$

$$\frac{336 \text{ kcal}}{7 \text{ km}} = 48 \text{ kcal/km}$$

Table 6 includes the various parameters surrounding the daily energy expenditure of 336-432 kilocalories per day (45). These values are comparable to others found in the literature. Paffenbarger et al observed health benefits with an expenditure of 357kcal/day (7). Booyens and Keatinge reported an expenditure of 38kcal/km for level walking at $6.44\text{km}\bullet\text{hr}^{-1}$ (28) and Howley et al. reported 35kcal/km expended while walking at 8.2km/min (46).

Table 6. Summary of Walking Parameters from Hatano's Study

	Slow Walking	Fairly Fast Walking	Fast Walking
Step Rate	100 steps/min	110	125
Speed	70m/min	88	106
Caloric Expenditure (middle size Japanese)	30 steps/kcal 3.2kcal/min	27 4.2	23 5.4
10,000 Steps (= daily target)	336 kcal 7.0 km	382 8	432 8.5

The corresponding MET values for these are 3.2 METS to 5.4 METS. One must also remember the average Japanese man is 165cm tall with an average weight of only 60kg (45). This is slightly different from the observed average American male who is approximately 65kg (15).

Future Implications

Walking is probably one of the easiest forms of exercise for the majority of the population. When looking at energy expended with walking and the health benefits associated with greater energy expenditure, there is definitely use for pedometers in our research. In a study conducted in Japan, those individuals with greater amounts of daily average walking demonstrated significant trends of decreased amounts of subcutaneous fat tissue and lower systolic blood pressure values (45).

Bassey and colleagues noted that for many elderly or sedentary people, walking is their only endurance activity (47). There is a definite public health concern with modern day automation, mechanization, and the widespread use of various electronic equipment. Their use may further reduce the low daily energy expenditure in certain individuals. Livingstone and colleagues found that recreational activity has now emerged as the key determinant of energy expenditure in most sedentary people. (48). Indirect calorimetry and time-and-motion studies are reliable methods for estimating physical activity but are inappropriate and not feasible for large-scale studies that gather data over a period of several days or weeks (15).

The use of the pedometer can alleviate this problem. It is easy to use, requires little effort from the individual, and has been shown to be accurate in measuring the number of steps and distance walked by individuals. Through the use of well validated equations, the number of steps walked at a given speed can then be converted to kilocalories expended. This would allow the pedometer to have useful applications in research studies focused on measuring one's level of activity and energy expenditure. It can greatly aid researchers and health professionals in monitoring physical activity while helping to promote the current exercise guidelines that incorporate a wider array of activities, which includes walking.

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