ABSTRACT

COMPARDO, J. L. The energy cost of stepping on the NordicSport Stepper in females. MS in Adult Fitness/Cardiac Rehabilitation, May 1995, 26 pp. (N.K. Butts)

This study evaluated exercise on the NordicSport Stepper (NSS), a hydraulic stepping system. Twenty-eighty females (age = 18-41 yrs) volunteered as subjects. Each subject completed 3, 5-minute workloads at resistance level 3 on the NSS. They stepped in time with a metronome set at predetermined rates of 48, 56, and 66 steps per minute (spm), respectively. During all exercise sessions HR and RPE were recorded and expired air was analyzed using an automated open-circuit gas system each minute. There were no significant (p > .05) differences among step rates for VO₂ (l·min⁻¹, ml·kg⁻¹·min⁻¹), RER, or kcal·min⁻¹. Heart rate was significantly (p < .05) lower at rate 48 compared to rates 56 and 64. Peak VO₂ and HR at rate 64 were 25 ml·kg⁻¹·min⁻¹ and 145 bpm. Step height was significantly (p < .05) lower at rate 64. Total work (step height x spm) was significantly (p < .05) different at each rate of stepping. At a constant workload of 3 on the NSS, variations in step rate did not affect VO₂, and thus, energy expenditure. Total work, however, significantly (p < .05) increased from the lowest stepping rate to the highest. A higher stepping rate, therefore, may indicate a more efficient stepping pattern since the total work increased without a significant increase in the oxygen demand of the exercise.
THE ENERGY COST OF STEPPING ON THE
NORDICSPORT STEPPER IN FEMALES

A MANUSCRIPT STYLE THESIS PRESENTED
TO
THE GRADUATE FACULTY
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE

BY
JILL L. COMPARDO
MAY 1995
**COLLEGE OF HEALTH, PHYSICAL EDUCATION AND RECREATION**  
**UNIVERSITY OF WISCONSIN-LA CROSSE**

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Candidate: Jill L. Compardo

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

**Master of Science in Adult Fitness/Cardiac Rehabilitation**

The candidate has successfully completed his/her final oral examination.

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ACKNOWLEDGEMENTS

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INTRODUCTION

In recent years the trend toward low or nonimpact aerobic exercise has become increasingly popular due to its health and physical fitness benefits and decreased risk of injury (Olson, Williford, Blessing, & Greathouse, 1990). This could be one reason why stepping machines have become one of the most popular exercise ergometers on the market today. There is a minimal amount of trauma to one's joints while stepping since the feet never leave the steps (Peterson, 1989).

There are many types of stepping machines currently available on the market including step treadmill devices and steppers. Step treadmills involve a series of revolving steps and, therefore, control step rate and vertical ascent. Steppers, which have peddles, allow for varied step rates at any fixed rate of vertical ascent (Howley, Colancino, & Swensen, 1992). However, there are two types of steppers: one functions by a computerized system and the other by a hydraulic system. Work on a computerized stepping system is accomplished by predominantly pressing down on the step and the step returns to its starting position automatically (Luketic, Hunter, & Feinstein, 1993). Only the concentric phase of stepping, therefore, should be considered when determining work done on this system. However, a hydraulic stepping system requires an up and a down phase of stepping. The mechanical differences involved between the computerized systems versus the hydraulic or human-powered systems could possibly alter the energy costs of stepping. The stepping rate and distance of each step on the hydraulic system, as well as the electronic stepper, are dependent on individual stepping techniques. The design of these steppers allows for either deep, slow steps or short, rapid steps to be performed at any given workload (Luketic et al., 1993). Most of the studies available on the energy cost of stepping involve the use of step treadmills and/or computerized

The purpose of this investigation was to evaluate the energy cost of exercise on the NordicSport Stepper (NSS) (NordicTrack, Inc., Chaska, MN), a hydraulic stepping system. The NSS is one of five aerobic exercise modalities featured on the NordicSport CrossTraining System (NSCT). To this date, there is a lack of sufficient information pertaining to the energy cost of hydraulic stepping.

METHODS

Subjects

Twenty-eight female subjects, ranging in age from 18 to 41 years, volunteered to participate in this study. Mean weight and height of the subjects were 58.7 kg and 165.1 cm, respectively. Prior to the testing session, each subject read and signed an informed consent form.

Testing Methodology and Instrumentation

A pilot study involving six subjects was conducted to determine the appropriate resistance level and cadence rates to be used for the testing protocol. No significant (p > 0.05) differences in VO₂ (ml·kg⁻¹·min⁻¹) were found among resistance levels 1, 3, 5, and 7 while stepping at a constant cadence rate of 48 steps per minute (spm) until steady state was reached at each level. The mean responses for VO₂ ranged from 17.1 ml·kg⁻¹·min⁻¹ at level 1, to 19.5 ml·kg⁻¹·min⁻¹ at level 7. Therefore, three, 5-minute workloads at resistance level 3 on the NSS were used for the actual testing sequence. Each subject stepped in time with a metronome set at low, medium, and high cadence rates of 48, 56, and 64 spm, respectively. Oxygen consumption was compared at each stepping rate. A brief practice session of 5 minutes was administered before the actual test to familiarize the subjects with the mechanics involved during stepping on an hydraulic
system. The subjects were instructed not to touch the handrails unless they lost balance.

Steady state was achieved at each level before progressing to the next level. A steady state was accepted when the relative oxygen consumption (ml·kg⁻¹·min⁻¹) did not deviate by more than 2.0 ml·kg⁻¹·min⁻¹ between the last 2 minutes of each stage. If steady state was not achieved during the 5 minute stage period, the stage was continued until steady state was reached. Step height was determined by placing a yard stick next to the pedals on the stepper to measure the vertical displacement of the steps. Reflective tape was placed on the back of the pedals for easier identification of the displacement. Step height was taken at the end of each steady state workload.

The Q-Plex I (Quinton Instrument Company, Seattle, WA), an automated open-circuit gas system, was used to collect and analyze the expired air and to calculate absolute and relative oxygen consumptions, kcal, and respiratory exchange ratios each minute. The Q-Plex I was calibrated prior to the testing of each subject using calibration gases of whose composition was determined by the micro-Scholander technique. The flow meter volume was calibrated using a 3.002 L syringe pump at various flow rates. Heart rates were monitored using UNIQ-CIC (Computer Instruments Corporation, Hemstead, NY) heart monitors. Rating of perceived exertion was recorded using the 6-20 Borg scale. Exercise heart rates (HR) were recorded each minute and rating of perceived exertions (RPE) were recorded at the end of each steady state workload. The average values of the last 2 minutes of the steady state period were used in all statistical analyses.

**Statistical Analyses**

Standard descriptive statistics were generated for absolute and relative oxygen consumptions (l·min⁻¹ & ml·kg⁻¹·min⁻¹), HR, ventilation (VE), respiratory exchange ratio (RER), kcal·min⁻¹, RPE, step height, and total work. A one-way analysis of variance with repeated measures was used to compare these responses among the three stepping rates at a significance level of 0.05. A Tukey's post hoc test was used to determine pairwise
differences.

RESULTS

Table 1 shows the effects of varied step rates (48, 56, and 64 spm) on the physiological responses to stepping at resistance level 3 on the NSS. There were no significant (p > 0.05) differences among the step rates for VO$_2$ (l·min$^{-1}$, ml·kg$^{-1}$·min$^{-1}$), RER, or kcal·min$^{-1}$. Heart rate was significantly (p < 0.05) lower at 48 spm compared to 56 and 64 spm. Step height was significantly (p < 0.05) lower at rate 64 versus rates 48 and 56. Total work, which was calculated by multiplying step height by the number of steps per minute, was significantly (p < 0.05) different at stepping rate.

DISCUSSION

This study evaluated the physiological responses of stepping on a hydraulic stepping system at various stepping rates. At a constant resistance of 3 on the NSS, the data clearly show that variations in step rate do not affect VO$_2$ (l·min$^{-1}$ and ml·kg$^{-1}$·min$^{-1}$), thus, energy expenditure (kcal). These findings are consistent with Howley et al. (1992) who reported no significant differences in VO$_2$ and HR responses to two varying step rates at three different fixed workloads on the StairMaster 4000. Howley et al. (1992) stated that this finding is consistent with what one might observe during grade-walking on a treadmill in which step rate is not viewed as an important variable affecting VO$_2$. A lack of significant difference between self-selected and cadence trials of VO$_2$ during StairMaster exercise was also reported by Butts et al. (1993).

The physiological responses to hand supported versus no hand support while exercising on a staistepping machine also vary. Butts et al. (1993) conducted a study on a StairMaster in which the subjects were instructed not to use their hands for support and found higher MET levels than those estimated by the company. Howley et al. (1992) compared HR and VO$_2$ values of "no hold," "light hold," and "heavy hold" treatments on the StairMaster 4000. No significant differences were found between the "no hold" and
Table 1. Physiological responses (mean and SD) to NordicSport stepping at 48, 56, and 64 spm at level 3 (N = 28).

<table>
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<tr>
<th>Variable</th>
<th>Stepping Rate</th>
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<tbody>
<tr>
<td></td>
<td>48</td>
<td>56</td>
</tr>
<tr>
<td>VO₂ (l\·min⁻¹)</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>VO₂ (ml\·kg⁻¹\·min⁻¹)</td>
<td>23.8</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>5.6</td>
<td>6.4</td>
</tr>
<tr>
<td>Heart Rate (beats\·min⁻¹)</td>
<td>130ᵃ</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>25.9</td>
<td>24.2</td>
</tr>
<tr>
<td>VE (l\·min⁻¹)</td>
<td>41.6</td>
<td>46.5</td>
</tr>
<tr>
<td></td>
<td>11.9</td>
<td>13.7</td>
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<tr>
<td>RER (VCO₂/VO₂)</td>
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<td>0.99</td>
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<tr>
<td></td>
<td>0.07</td>
<td>0.07</td>
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<tr>
<td>Kcal\·min⁻¹</td>
<td>7.1</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>RPE</td>
<td>10.1</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Step height (inches)</td>
<td>6.1</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Total work (feet)</td>
<td>24.6ᶜ</td>
<td>27.2ᶜ</td>
</tr>
<tr>
<td></td>
<td>40.7</td>
<td>55.1</td>
</tr>
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ᵃ HR at rate 48 significantly (p < 0.05) lower than at rates 58 and 64.
ᵇ Step height at rate 64 significantly (p < 0.05) lower than at rates 48 and 56.
ᶜ Total work significantly (p < 0.05) different among all work rates.
"light hold" conditions at lower work rates. However, significantly lower values were found in the "heavy hold" treatment at the 10-MET level. Bideaux, Wygand, Otto, Helgemore, and Kosilla (1991) also found small but significant differences in VE, VO₂, and HR during nonsupported versus supported stepping on the StairMaster. Holding onto the handrails in such a way that body weight is supported may cause an overestimation of VO₂ max and fewer kilocalories may be expended. Therefore, in order to maximize caloric expenditure on the NSS, the subjects in the present study were instructed not to touch the handrails unless they lost balance.

The NSS is a hydraulic stepping system which applies resistance in two forms. Resistance is applied through the air resistance of the hydraulics themselves and also by a pulley system. Thus, steps taken on the NSS are dependent on each other due to the pulley system. As a consequence, a person can self-select the rate of stepping regardless of the resistance level. For example, a subject can shift the weight to force the pedal down gradually or rapidly. The more weight which is shifted, the more rapidly the step will descend which will, therefore, increase the vertical displacement of the steps. Because of this, the subject is able to increase or decrease the workload at any given resistance level. It is then possible to vary step height while maintaining the appropriate cadence rate.

Due to the mechanics involved with the hydraulic stepping system, a subject's stepping technique has a direct influence on the vertical displacement of the steps. It was observed that the subjects, while maintaining the stepping cadence, were able to take deep or short steps to complete each of the workloads. As the cadence rate increased, there was a trend toward decreasing step height with the step height at rate 64 significantly lower than step height at rates 48 and 56 (see Table 1). The influence of step height on the energy cost of bench stepping was investigated by Olson et al. (1991). They studied the effects of stepping at four different bench heights on VO₂ and found that the oxygen requirement increased significantly from the lowest bench height to the highest. Stepping
at a higher bench height may require more contribution from the larger muscles of the lower body and, therefore, increase energy expenditure. The shorter steps taken at the two highest cadence rates on the NSS could be one possible explanation for the lack of significant difference in VO₂ and kcal·min⁻¹ found at each of the workloads in the present study.

Step height decreased as cadence rate increased; however, total work done on the NSS significantly (p < 0.05) increased from the lowest cadence rate to the highest. Total work was 24.6, 27.2, and 29.5 feet per minute at 48, 56, and 64 spm, respectively. Total work was calculated by multiplying step height by the number of steps per minute. Even though the distance of each step was shorter, total work done increased as the cadence rate increased thus the subjects covered more distance without a significant increase in oxygen consumption. A higher stepping rate, therefore, may indicate a more efficient stepping pattern since the total work was increased without a significant increase in the oxygen demand of the exercise.

Oxygen demand during activity, however, varies among individuals. Thomas, Weller, and Cox (1993) concluded that at most one-third of the variability in oxygen consumption during a stepping task may be accounted for by subject characteristics. These characteristics included age, leg length, and VO₂ max with age having the strongest correlation with oxygen demand for women. This relationship may arise if the older subjects do more work when stepping vigorously or if they use more energy to perform the same work. Cicutti, Jette, and Sidney (1991) also studied the effect of leg length on bench stepping efficiency by varying the step height to correspond to 30, 40, and 50% of individual leg length while maintaining a constant exercise load. No significant differences were found, however, in VO₂, HR, or VE among the three stepping conditions.

Nagle, Balke, and Naughton (1965) proposed that the relative oxygen requirement in stepping is primarily dependent upon the stepping rate and to a lesser extent on stepping
In order for exercise to enhance cardiorespiratory fitness and health, the activity
mechanics, and the HR remained only 5 beat/min higher than the HR at 76 rpm.
A rate of 64 the subjects were then familiarized with the stepping
significant increase in HR. At rate 64 the subjects were then familiarized with the stepping
increase in the pumping action of their arms. These two factors may have caused the
rate increased to 96 rpm. The subjects had to stop faster which required more balance and
significant lower at rate 48 due to the extremely slow stepping cadence. As the cadence
difference was found in VO2 among the three rates of stepping. Heart rate may have been
significantly lower (p > 0.05) lower than that at rates 56 and 64. However, no significant
College of Sports Medicine, 1991.

In this study, the exercise HR at rate 48 was
oxygen uptake increases progressively as a function of exercise intensity (American
Heart rate rises in a linear fashion as a function of increased oxygen uptake and
stepping exercise among most subjects on an hydraulic stepping system. This may have increased the RER values. These findings may also have been due
and VO2 max of the lack of system. This may have increased the RER values. These findings may also have been due
familiarize the subjects with the proper mechanics used during stepping on an hydraulic
were met, however, an extended practice session may have been necessary to completely
inadequate or to the lack of local muscular adaptation to stepping. Steady state criteria
that most subjects were exercising anaerobically. This may be contributed to stepping
rate (1.00, 0.99, and 0.97 at 48, 56, and 64 rpm, respectively) in this study, it is evident
age, leg length, and VO2 max. Based on the RER values of the subjects at each stepping
steppeficiency among individuals may not always be constant. Due to such factors as
1996). However, it has been previously demonstrated by Thomas et al. (1993) that
efficiency among individuals, relative VO2 tends to vary little individually (Nagle et al).
height, rather than absolute workload. Under the assumption of a uniform workload

null hypothesis of 40 to 85% of maximal oxygen consumption (VO2 max), and be rhythmic and
aerobic in nature (ACSM, 1991). The highest work level administered in this study on the NSS elicited a \( V_O_2 \) of 25.8 ml·kg\(^{-1}\)·min\(^{-1}\). Therefore, a highly unfit individual would be able to achieve the recommended intensity on the NSS to enhance cardiorespiratory fitness and health.

Stairstepping utilizes the large muscle groups in the back, buttocks, and lower legs and can offer a high-intensity workout for a prolonged period of time (DeBenedette, 1990). It can be concluded, therefore, that stairstepping may be an excellent exercise modality for achieving aerobic fitness in some individuals. It must be recognized, however, that a hydraulic system of the same type as the NSS involves the use of different mechanical systems while stepping. It was found that varying the resistance level or the cadence rate had no effect on \( V_O_2 \). Therefore, when exercising on such a system, it is recommended that the machine be set at a resistance level in which the individual can step at a comfortable cadence rate while using no-hand support.
REFERENCES


APPENDIX A

INFORMED CONSENT FORM
Informed Consent Form

Project Title: The Energy Cost of Stepping on the NordicSport Stepper in Females.

Principal Investigator: Jill Compardo

I, __________________________, volunteer to be a subject in a project to determine the energy cost of the NordicSport Stepper, which is a hydraulic stepping system. Participation in this study requires that I complete a series of submaximal tests on a stepping machine (NordicSport Stepper).

Prior to the actual test, I will be required to practice stepping on the NordicSport Stepper in order to familiarize myself with the mechanics and coordination involved to complete the test. I also understand that the testing session will be scheduled at both my convenience and the convenience of the researcher.

The submaximal test will consist of 3, 5 minute continuous bouts of stepping. At the end of each consecutive bout, the cadence rate will be increased. During the test my exhaled air will be collected and heart rate monitored. I understand that I can stop the test at any time. As with any exercise, there is the possibility that adverse changes may occur (i.e. dizziness, shortness of breath, etc.) during this test. If any abnormal observations are noted at any time, the test will be immediately terminated.

I consider myself to be in good health and do not have any physical condition or disability, especially with respect to my heart, that would preclude my participation in the study. I have read the foregoing and understand what is expected of me. I, therefore, consent to, authorize and request the person named above to undertake and perform on me the proposed procedure. I have been fully advised of the nature of the procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume responsibility. I hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to the procedure have been made to me by the University of Wisconsin - La Crosse, the officers, administration, employees or by anyone acting on behalf of them. I understand that I may withdraw from the study at any time.

Signed: __________________________ Date: __________________________

Witnessed: __________________________ Date: __________________________
APPENDIX B
RESEARCH QUARTERLY FOR EXERCISE AND SPORT
GUIDELINES FOR CONTRIBUTORS
Guidelines for Contributors

Research Quarterly for Exercise and Sport publishes research in the art and science of human movement that contributes to the knowledge and development of theory either in new formulations, refinement, or elucidation, or in the construction of previous findings or as application of newer improved techniques. Articles must conform to the technical details set forth in this guide. Manuscripts must be clear, logical, and written in the briefest form that will adequately address the content. AGS also publishes research notes, a dialogue section, and book reviews.

The editor is assisted by the editorial board, the section editors, and external reviewers. Manuscripts deemed suitable are referred to qualified reviewers in the appropriate subdivisions. Authors are usually advised of the decision on their papers within 75 to 90 days.

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Manuscripts should be typed, double-spaced, on 8½ x 11 inch paper. Authors are encouraged to include line numbers within the margins of the text. If a word processor has been used, general papers should not exceed 28 pages, including references and tables. Longer papers may be accepted for multiple studies, reviews, and concept areas such as sociocultural, historical, or philosophical research. On the final acceptance of a manuscript, authors who have prepared manuscripts on a word processor or computer will be requested to submit a copy of the computer disk with the file stored as TEXT (ASCII) code. Manuscripts must conform to the Publication Manual of the American Psychological Association (6th ed.). Figures and tables must meet the guidelines in the APA style guide (see Sections 3.50-3.55).

The manual may be ordered from the Order Department, American Psychological Association, P.O. Box 2710, Hystsville, MD 20741. (Authors of historical articles should follow the University of Chicago Manual, 14th ed.) Manuscripts deviating from the recommended formats will neither be reviewed nor returned.

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Research Notes, Comments, and Dialogue

Research Quarterly for Exercise and Sport welcomes research notes of no longer than 12 manuscript pages, including texts, references, figures, and tables. Certain types of papers are classified as research notes, such as replications, test development, equipment development, computer programs, profile evaluations, brief communications, data analysis, and document verification. Papers submitted as research notes should be so indicated. Abstracts are not submitted with research notes, but key words must be included on the cover page (both original and blind cover). Brief comments and dialogue on previously published papers are also encouraged. For additional details see "Editor's Viewpoint" in the March 1985 issue of RQES.

Authors

Multiple authors should be listed in the order of proportionate work commitment. Research reports supported by grants and contracts should be so indicated. Biographical information on all authors (title, department, institution or company, address) must be included. Manuscripts submitted to RQES must not be submitted concurrently to other journals.

Blind Reviews

Since reviews are blind, authors must include a second cover page that contains only the title, running head, and header. It must include no reference to authors or funding agency. The title should also appear at the top of the abstract sheets, but the author(s) name(s) should not appear in the manuscript except as a reference citation.

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APPENDIX C

REVIEW OF LITERATURE
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In recent years, crosstraining has become increasingly popular among fitness enthusiasts. The NordicSport CrossTraining System Manual (1993) defines aerobic crosstraining as the incorporation of two or more aerobic exercises in a personal fitness program. The crosstraining system, manufactured by NordicSport (NordicTrack, Inc., Chaska, Mn), offers five aerobic exercises in one space-efficient machine. These exercises include walking, jogging, "NordicWalking" power walking, cross-country skiing, and staiirstepping.

Stairstepping has become a popular aerobic exercise mode among many. In order for exercise to enhance cardiorespiratory fitness and health, the activity must use large muscle groups, be continuously or discontinuously maintained for 15 to 60 minutes in duration, achieve an intensity of 40 to 85% of maximal oxygen consumption (VO₂ max), and be rhythmic and aerobic in nature (ACSM, 1991). Stairstepping utilizes the large muscle groups in the back, buttocks, and lower legs and can offer a high-intensity workout for a prolonged period of time (DeBenedette, 1990). Therefore, it can be concluded that stairstepping may be an excellent exercise modality for achieving aerobic fitness in some individuals. The energy cost of stepping, however, is an important and useful measurement among exercisers that wish to monitor their energy expenditure. Most of the studies available on the energy cost of stepping involve the use of step treadmills and/or computerized steppers (Butts, Dodge, & McAlpine, 1993; Hanson, Wiswell, & Girondola, 1989; Kohn, Hurley, & Wygand, 1991; Riddle & Orringer, 1990; Verstraete & Bassett, 1989).

As previously stated, the NordicSport CrossTraining System offers stairstepping as one of the five exercises included on the apparatus. The following is a review of literature
in the following areas: (1) the measurement of energy cost; (2) stairstepping as an effective training and testing modality; and, (3) the physiological differences between no arm support and arm support while stairstepping. Because the NordicSport CrossTraining System has just been manufactured, the literature did not contain information directly related to the energy cost of the Stepper. This lack of information is the reason for this investigation.

Energy Measurement

There are three major components of energy expenditure which include resting metabolic rate (RMR), thermic effect of feeding (TEF), and thermic effect of activity (TEA) (Brownell, Rodin, & Wilmore, 1992). The RMR is the total amount of energy expended while at rest. The TEF is the energy expended, above the RMR, required to digest, absorb, and metabolize foodstuffs. The energy expended during muscular activity, such as physical exercise, is defined as the TEA.

Energy expenditure can be measured by direct and indirect calorimetry. Direct calorimetry involves the measurement of the amount of heat generated or lost by the body within a closed system. This method is based on the fact that all the processes that occur within the body result ultimately in the production of heat (McArdle, Katch, & Katch, 1991). Therefore, by measuring heat loss or gain by the body, energy expenditure can be determined. Because this method is expensive and impractical for exercise, indirect calorimetry is more commonly used.

Indirect calorimetry estimates energy production by measuring oxygen consumption and carbon dioxide production versus measuring heat transfer (Brownell et al., 1992). McArdle et al. (1991) stated that all energy metabolism in the body ultimately depends on the utilization of oxygen. Thus, by measuring an individual's oxygen consumption at rest and under steady-rate exercise conditions, it is possible to obtain an indirect estimate of energy metabolism because the anaerobic energy yield is very small
under such conditions. An "open circuit" method is used most commonly for this measurement. The expired and inspired air is collected and analyzed for oxygen and carbon dioxide content. A steady state of carbon dioxide and respiratory exchange must be reached for this method. The indirect method of calorimetry expresses energy expenditure in one of three ways: (1) the total amount of oxygen consumed (VO₂); (2) the respiratory exchange ratio (RER); and, (3) the MET or metabolic equivalent level.

**Oxygen Consumption and Steady State**

Oxygen utilization by the body during metabolism allows researchers to measure the energy requirements of different activities (Hanson et al., 1989). To accurately measure energy cost, however, a steady state must be reached. Oxygen consumption during steady state exercise can be used to calculate the energy cost of that exercise. Steady state is achieved when the body is meeting the demand for oxygen uptake, waste product removal, and temperature regulation while performing an activity. Butts et al. (1993) in a study comparing the effects of StairMaster stepping rates on energy cost, accepted a steady state when the VO₂ (ml·kg⁻¹·min⁻¹) did not deviate by more than 1.0 ml·kg⁻¹·min⁻¹ between the last 2 minutes of each 5 minute stage.

Oxygen demand during activity, however, varies among individuals. Thomas, Weller, and Cox (1993) concluded that one-third of the variability in oxygen consumption during a stepping task may be accounted for by subject characteristics. These characteristics included age, leg length, and VO₂ max. Cicutti, Jette, and Sidney (1991) also studied the effect of leg length on bench stepping efficiency by varying the step height to correspond to 30, 40, and 50% of individual leg length while maintaining a constant exercise load. No significant differences were found, however, in VO₂, HR, or VE among the three stepping conditions. Nagle, Balke, and Naughton (1965), however, proposed that the relative oxygen requirement in stepping is primarily dependent upon the stepping rate and to a lesser extent on stepping height, rather than absolute workload. Under the
assumption of a uniform working efficiency among individuals, relative VO₂ tends to vary little individually.

**Respiratory exchange ratio (RER).** When measuring oxygen consumption, a direct relationship can be made with the ability to aerobically oxidize foodstuffs. From the analysis of expired gases using the indirect method of calorimetry, the foodstuff used to form ATP can be determined (McArdle et al., 1991). The foodstuff used is determined by calculating an individual's RER, the ratio of carbon dioxide produced to oxygen consumed. The body requires different amounts of oxygen to oxidize the carbon and hydrogen atoms in various foodstuffs such as carbohydrates, fats, and proteins. However, when using RER values to calculate energy expenditure in kcals, it is assumed carbohydrates and/or fats are being utilized for energy. The RER values for the oxidation of pure carbohydrates and fats are 1.00 and 0.70, respectively.

In relation to exercise intensity, exhaustive or anaerobic exercise may cause the RER to move toward or above 1.00. During anaerobic exercise, lactic acid is generated and buffered by sodium bicarbonate in the blood in order to maintain proper acid-base balance. This process adds extra carbon dioxide to the quantity normally released during energy metabolism and causes the RER to move toward 1.00 (McArdle et al., 1991). During aerobic exercise, however, more oxygen is available in order to oxidize fat to carbon dioxide and water. Therefore, the RER may move toward 0.70 while exercising aerobically.

**Metabolic equivalent (MET).** METs can also be used to express the average workload of various activities. A MET is defined as the amount of oxygen consumed per kilogram of body weight. One MET is equal to approximately 3.5 ml·kg⁻¹·min⁻¹. To calculate the MET level of an activity, oxygen consumption in ml·kg⁻¹·min⁻¹ must be divided by 3.5 ml·kg⁻¹·min⁻¹. MET levels of activities are commonly used and can be easily interpreted by many individuals.
There are many stepping machines on the market today. The StairMaster 4000PT, the StairMaster 6000, the Gauntlet, and various human-powered steppers are among these popular pieces of exercise equipment. However, can these machines be used effectively as training and testing tools? The stair-treadmill devices, which include the StairMaster 6000 and Gauntlet, operate in a continuous mechanical stepping pattern which does not require the subject to step down (Hanson et al., 1989). Because of this, negative work has been eliminated. Therefore, work performed can be more accurately measured. Hanson et al. (1989) determined the oxygen consumption of subjects performing 4, 4-minute bouts on the StairMaster 6000 and then on actual stairclimbing. No significant oxygen consumption differences were found among the two testing modalities. Holland, Hoffman, Vincent, Mayer and Caston (1990) compared maximal step-treadmill and treadmill responses. Virtually identical peak responses were achieved in both modes. Luketic, Hunter, and Feinstein (1993) found peak VO₂ values for the StairMaster which compared favorably with the values of Holland et al. (1990). Both Hanson et al. (1989) and Holland et al. (1990) concluded that stairclimbing is a viable alternative mode for testing subjects. Olson, Williford, Blessing, and Greathouse (1991) studied the cardiovascular and metabolic effects of bench stepping in females. They concluded that aerobic bench stepping is also an exercise modality that provides sufficient cardiorespiratory demand for enhancing aerobic fitness and promoting weight loss in females.

It has been stated that stairclimbing is a reliable means of testing. However, is this form of exercise an appropriate training modality? Loy and Holland (1990) studied the training effects of the StairMaster Gauntlet versus running. After 9 weeks of training subjects, both modalities achieved demonstrative improvement on the subject's 1.5 mile run time and VO₂ max measurements. Rosentewieg, Verstraete and Bassett (1986) also
studied the training effects of stairclimbing. After 12 weeks of training, the subjects showed an increase in V̇O$_2$ max of 36%. This was found to be comparable to increases determined for walking, running, and cycling.

Achieving overall aerobic fitness, including increases in strength, cardiovascular endurance, and lean body mass, is among the goals of many fitness enthusiasts. Use of the StairMaster 4000PT has been shown to be an effective means for not only improving cardiovascular endurance but also improving leg strength and increasing the level of energy expenditure (Peterson, 1989). Stepping offers a low trauma and safe exercise mode. "Stairclimbing is a very basic exercise but extraordinarily effective. A number of recently completed research studies have confirmed the fact that the StairMaster 4000PT exercise system offers a highly productive means for developing aerobic fitness " (Peterson, 1989).

**Hand Supported versus Nonsupported Stepping**

The physiological responses to hand supported versus no hand support while exercising on a stairstepping machine vary. Butts et al. (1993), in a StairMaster study in which the subjects were instructed not to use their hands for support, found higher MET levels than those estimated by the company. Howley et al. (1992) compared heart rate and VO$_2$ values of "no hold", "light hold," and "heavy hold" treatments on the StairMaster 4000 step ergometer. No significant differences were found between the "no hold" and "light hold" conditions at lower work rates. However, significantly lower values were found in the "heavy hold" treatment at the 10-MET level. Bideaux, Wygand, Otto, Helgemore, & Kosilla (1991) compared supported versus nonsupported StairMaster climbing at 6, 8, 10, and 12 METs. Small but significant differences between matched workloads in ventilation, oxygen consumption, and heart rate were found. Butts et al. (1993) and DeBenedette (1990) suggested that leaning on the armrests of a stair machine transfers less weight to the pedals and results in an overestimation by the stairclimbing
computer of caloric expenditure. Unpublished data by Butts (1993) concluded that the METs obtained during hand supported or leaning positions compare more favorably to those suggested by the company.

The previous findings have been found to be consistent with handrail versus no handrail support during treadmill exercise. Beadle, Holly, and Amsterdam (1990) compared treadmill walking at four different speeds using hand support and no hand support. Reduced oxygen consumption values were found during hand supported versus no hand support on the treadmill. In conclusion, in order to achieve a higher MET level or energy expenditure during stairclimbing, one should not hold on to the supports.

Summary

In conclusion, stepping ergometers have become one of the most popular exercise modalities on the market today. The energy cost of stepping, therefore, is an important and useful measurement. Energy expenditure, when measured indirectly, can be expressed in terms of the total amount of oxygen consumed, the RER, and/or the MET. Stair-treadmills and steppers have also been found to be a viable alternative mode for testing and training subjects. Stepping has been shown to be an effective means for not only improving cardiovascular endurance, but also improving leg strength and increasing one's level of energy expenditure.
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