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Original Research Article

A Comparison of Energy Expenditure when Exercising on 10 Indoor Exercise Machines

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Abstract

Introduction: There are a growing number of indoor exercise machine options available to consumers. As exercise professionals we are often asked which is the "best" exercise machine. The best exercise machine is often considered to be the one that results in the greatest level of energy expenditure (EE) during exercise. **Purpose:** To compare EE between 10 exercise machines to determine which one burns the most calories. **Methods:** Sixteen apparently healthy volunteers (8 males and 8 females) completed exercise bouts on a motorized treadmill (TM), step mill (ST), Airdyne (AD), elliptical (EL), upright bike (UB), Cybex arc trainer (CY), rower (RO), recumbent stepper (RS), recumbent bike (RB), and arm ergometer (AE). On each machine, subjects completed 5-minute exercise bouts at workloads that elicited RPE levels of 11, 13, and 15 on the 6-20 Borg scale. Oxygen consumption (VO_2) was measured directly during all testing and converted to EE (kcal/min). **Results:** Overall, EE values on TM and ST were significantly higher than all of the other machines. EE values on AD, EL, UB, CY, and RO were significantly higher than RS, RB, and AE. AE resulted in the lowest EE. **Conclusions:** If someone's goal is to maximize EE, exercising on a TM or ST is the best option. However, the other machines can provide a variety of benefits, depending upon individual goals.

Key Words: Caloric Expenditure, Perceived exertion, Training Intensity

Introduction

The incidence of cardiovascular disease, diabetes, obesity and other chronic health conditions continues to increase in the United States[1]. It is well known that regular physical activity reduces cardiac risk factors and can positively affect many of these disease states[2]. The Despite this knowledge, only 23% of adults in the United Sates currently meet recommended guidelines for physical activity[1]. One of the main reasons cited for not exercising is lack of time. Since many of the health-related benefits of exercise are related to daily or weekly energy expenditure goals, identifying the exercise machine that expends the most energy in the shortest period of time would be beneficial. This would optimize energy

expenditure and minimize the time need to be spent exercising.

A number of studies have compared EE when exercising on a variety of indoor exercise machines. A common way to compare exercise intensity between modalities is by having subjects exercise at matched rating of perceived exertion (RPE) levels. Zeni, Hoffman and Clifford[3] assessed EE on a treadmill, AirDyne, cross-country ski simulator, cycle ergometer, rowing ergometer, and stair stepper at RPE levels of 11, 13, and 15. They found that the treadmill produced the highest EE and concluded that the treadmill is the best indoor exercise machine when RPE is used to guide exercise intensity. Similarly, Moyna et al.[4] compared EE among six different aerobic machines at RPE intensities of 11, 13, and 15. They found that EE was highest on the treadmill and the cross-country ski machine in men and the treadmill, ski simulator, and rower in women.

Several studies have found that exercising on a treadmill and an elliptical machine produce similar physiological responses. Brown et al.[5] and Porcari, Foster, and Schneider[6] measured EE during exercise on a treadmill and an elliptical trainer at self-selected submaximal intensities. They found no significant differences in EE or oxygen uptake (VO_2) between the two modalities. Dalleck, Kravitz, and Robergs[7] found that the treadmill and elliptical machine produced similar maximal oxygen uptake (VO_2max) values. Finally, Egana and Donne[8] found that VO_2max measured on a treadmill, elliptical, and stair climber were not significantly different from each other.

Hill et al.[9] compared VO_2 during 20-minute submaximal exercise bouts on a treadmill, cycle ergometer, and an arm ergometer. They found that VO_2 on the treadmill was 13% higher than on the cycle ergometer and 52% higher on the arm ergometer. They concluded that exercising on the treadmill yielded the highest EE because both cycling and arm ergometry are non-weight bearing exercises that utilize a smaller muscle mass.

Several studies also compared EE and O_2pulse when exercising on a cycle ergometer and a rowing machine. Bouckaert, Pannier, and Vrijens[10] found that the rowing machine produced lower VO_2max and maximal O_2pulse responses compared to the cycle ergometer. Mahler, Andrea, and Ward[11] also found that VO_2max was significantly greater on the cycle ergometer compared to the rowing machine. Conversely, Hagerman, Lawrence, and Mansfield[12] concluded that EE on the rowing machine was significantly higher than the stationary cycle.

As seen, there are conflicting results between studies and most studies only compared a limited number of modalities. Additionally, there are a growing number of newer aerobic exercise machines on the market that are being used by consumers. The purpose of this study was to compare EE among 10 indoor exercise machines in an attempt to identify the "best" aerobic exercise machine. The 10 machines compared were a treadmill (TM), step mill (ST), AirDyne (AD), elliptical (EL), upright bike (UB), Cybex arc trainer (CY), rower (RO), recumbent stepper (RS), recumbent bike (RB), and arm ergometer (AE).

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Methods

Participants

Sixteen heathy adults between 18-25 years of age participated in this study. All subjects were free from known cardiovascular, metabolic, or pulmonary disease, and did not have any musculoskeletal contraindications to exercise. All subjects provided written informed consent before undergoing any testing or training procedure. The study was approved by the University's Institutional Review Board for the Protection of Human Subjects. Descriptive characteristics of the subjects are presented in Table 1.

Table 1. Descriptive characteristics of the subjects (N=16).

	Male (n=8)	Female (n=8)
Age (yr)	22.4 ± 0.9	22.0 ± 1.6
Height (cm)	179.8 ± 4.1	165.1 ± 8.6
Weight (kg)	82.6 ± 6.2	64.0 ± 7.9
BMI	25.5 ± 1.4	23.6 ± 3.2

Values represent mean ± standard deviation.

Procedures

Subjects received standard instructions on the use of the 6-20 Borg RPE scale[13]. Each subject then performed 3-5 practice sessions on each of the 10 exercise machines. The 10 exercise machines were a Matrix T5X motorized treadmill (TM), Life Fitness Power Mill stepper (ST), Schwinn AirDyne (AD), Matrix A5X elliptical (EL), Monark 828 E upright bike (UB), Cybex Arc Trainer (CY), Concept 2 rower (RO), SCIFIT Step One recumbent stepper (RS), Precor RBL 835 recumbent bike (RB), and a SCIFIT Pro 2 arm ergometer (AE). During the practice sessions, subjects self-selected workloads that elicited RPE levels of 11, 13, and 15, which correspond to the verbal anchors of "light", "somewhat hard", and "hard" on the 6-20 Borg scale. Subjects practiced for approximately 5 minutes at each RPE level. On the machines that were most familiar to them (e.g., treadmill), subjects may have only completed three practice sessions. On machines with which they were less familiar (e.g., Cybex Arc Trainer), subjects typically completed five practice sessions. The number and length of the practice sessions was at the discretion of the research assistant conducting the study. Subjects practiced on two machines on each practice day.

All subjects were tested on all 10 machines. Each subject completed five testing sessions, with each session conducted on a separate day. There was a minimum of 48 hours between testing sessions. During each testing session, subjects exercised on two machines, in random order. On each machine, subjects warmed-up for 3 minutes at 75% of the work rate corresponding to RPE 11. They then performed 5-minute exercise bouts at RPE 11, 13, and 15, in that order, with no break between RPE levels. This was followed by a 3-minute cool-down at the same workload as the warm-up. During the first 3 minutes of each stage, subjects were able to adjust the workloads to match the desired RPE level. Subjects then rested for 15 minutes and repeated the exercise sequence on the second machine.

During each exercise bout, HR was recorded each minute using radiotelemetry (Polar Electro

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Oy, Kempele, Finland), RPE was assessed at the end of each stage using the 6-20 Borg scale, and VO_2 was continuously measured using an Oxycon Mobile™ (CareFusion, Yorba Lina, Ca) portable metabolic system. This system was calibrated before each test with gases of known concentrations (16.02% O_2, 4.00% CO_2) and with room air (20.93% O_2 and 0.03% CO_2) as per manufacture guidelines. Calibration of the pneumotachometer was done via a 3 liter calibration syringe (Hans-Rudolph, Kansas City, MO). Energy expenditure was calculated from the VO_2 data, assuming a constant of 5 kcal for each liter of O_2 consumed.

Statistical analyses

Standard descriptive statistics (mean ± standard deviation) were used to characterize the subject population and to summarize the data. Initially, a two-way ANOVA was run to compare HR, VO_2, and EE between machines and RPE levels. There was a significant main effect for modality and there was also a significant interaction. Thus, comparisons of the responses between the 10 machines at each RPE level were made using one-way ANOVA with repeated measures. If there was a significant F-ratio, difference between specific machines were made using Tukey's post-hoc tests. Alpha was set at 0.05 to achieve statistical significance. Data were analyzed using SPSS version 25.0 (Chicago, IL).

Results

The HR responses when exercising on each of the 10 machines at each RPE level are presented in Table 2 and Figure 1, respectively. There were significant differences in HR between machines, with values varying by up to 46 beats per minute at a given RPE. Specific between machine differences at each RPE are indicated in Table 2. However, as can be seen in Figure 1, generally TM and ST exercise elicited the highest HR at each RPE. This was followed by EL, CY, UB, RO, and AD. RS, RB, and AE resulted in somewhat similar HR responses.

Table 2. Heart rate responses (bpm) at RPE 11, 13, and 15 on the 10 exercise machines (mean ± SD).

Machine	RPE11	RPE13	RPE15
Treadmill	136 ± 20.0	159 ± 13.6	173 ± 12.7
Stair Stepper	144 ± 17.0	162 ± 16.0	173 ± 14.2
AirDyne	119 ± 16.7[abdf]	137 ± 17.1[ab]	160 ± 14.0[ab]
Elliptical	133 ± 16.2[b]	145 ± 13.7[ab]	159 ± 12.0[ab]
Upright Bike	129 ± 14.6[b]	147 ± 15.8[ab]	161 ± 14.7[ab]
Cybex Arc Trainer	138 ± 21.5	150 ± 19.0[b]	161 ± 17.4[ab]
Rower	118 ± 12.4[abdf]	132 ± 13.5[abdef]	148 ± 16.5[abcefd]
Recumbent Stepper	98 ± 16.0[abcdefg]	117 ± 15.9[abcdefg]	136 ± 19.2[abcdefg]
Recumbent Bike	109 ± 14.2[abdef]	122 ± 16.2[abcdef]	137 ± 18.0[abcdefg]
Arm Ergometer	102 ± 16.0[abcdefg]	116 ± 14.8[abcdefg]	131 ± 17.0[abcdefg]

[a] Significantly lower than Treadmill ($p < .05$).
[b] Significantly lower than Stair Stepper ($p < .05$).
[c] Significantly lower than AirDyne ($p < .05$).
[d] Significantly lower than Elliptical ($p < .05$).
[e] Significantly lower than Upright Bike ($p < .05$).
[f] Significantly lower than Cybex Arc Trainer ($p < .05$).
[g] Significantly lower than Rower ($p < .05$).

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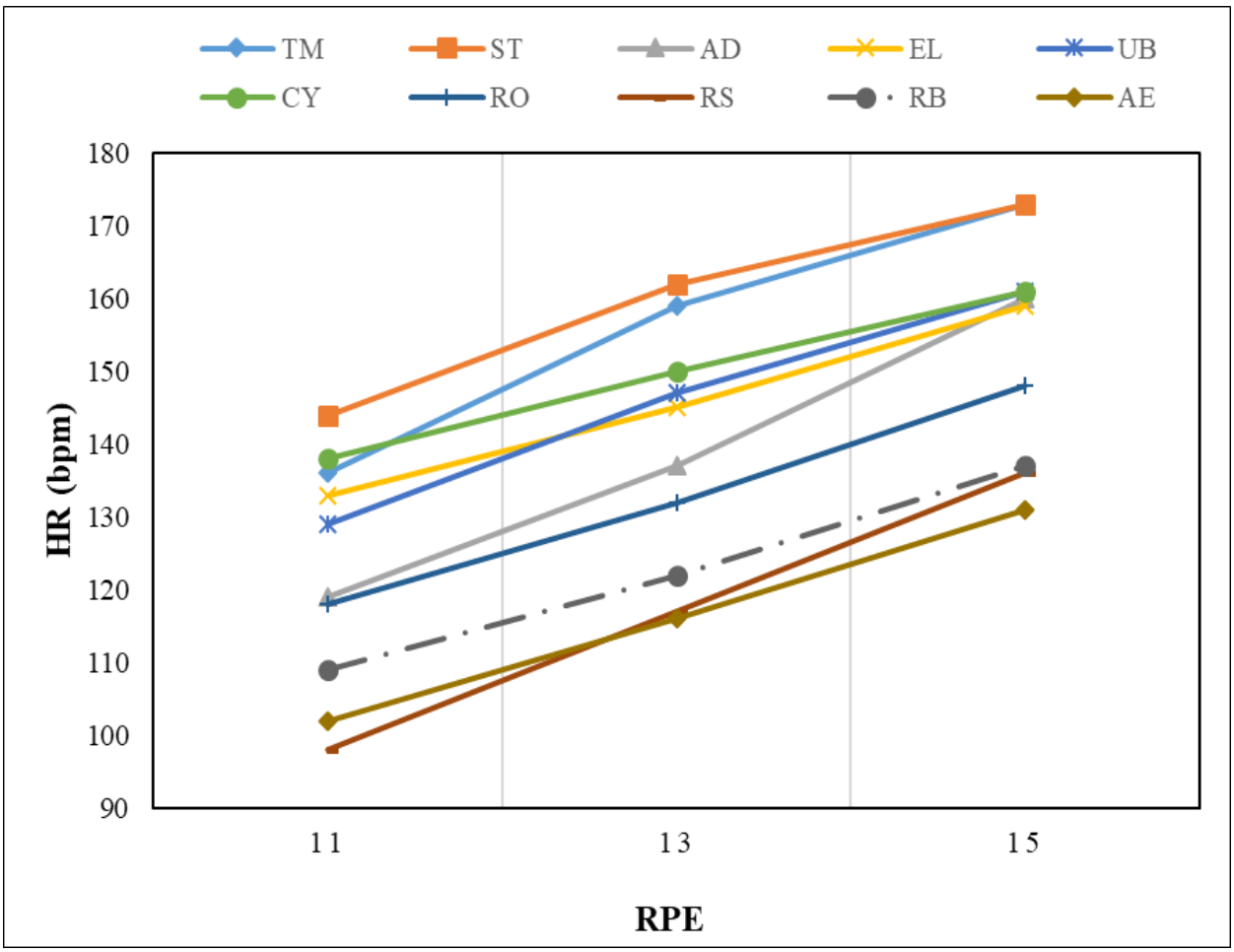

Figure 1. Heart rate (HR) (bpm) on the 10 exercise machines at RPE levels of 11, 13, and 15.

The VO_2 responses when exercising on each machine at each RPE level are presented in Table 3. The EE data at each RPE level are presented in Table 4 and Figure 2, respectively. Because the EE data were calculated directly from the VO_2 data, the between machine differences at each RPE level are the same for both variables. While there were differences in EE between machines (indicated in Table 4), the data generally fell into four distinct groupings. Thus, EE for each machine, collapsed across RPE, are presented in Figure 3. TM and ST elicited significantly higher EE than all of the other modalities. EL, UB, CY, AD, and RO were significantly greater than RB, RS, and AE. RB and RS were significantly greater than AE.

Table 3. Oxygen consumption (ml/kg/min) responses at RPE 11, 13, and 15 on the 10 exercise machines (mean ± SD).

Machine	RPE11	RPE13	RPE15
Treadmill	26.3 ± 6.8	34.5 ± 6.0	39.0 ± 7.4
Stair Stepper	27.5 ± 3.9	32.3 ± 4.2	35.8 ± 4.8[a]
AirDyne	21.0 ± 3.4[abd]	25.8 ± 4.7[ab]	33.2 ± 5.9[a]
Elliptical	24.6 ± 4.2[b]	28.2 ± 5.3[ab]	32.1 ± 5.8[ab]
Upright Bike	22.5 ± 4.1[ab]	27.1 ± 5.2[ab]	31.7 ± 6.0[ab]
Cybex Arc Trainer	23.6 ± 4.7[ab]	27.2 ± 5.3[ab]	31.1 ± 6.6[ab]
Rower	23.6 ± 4.7[ab]	25.2 ± 6.1[ab]	30.2 ± 8.2[ab]
Recumbent Stepper	13.6 ± 3.9[abcdefg]	19.4 ± 4.8[abcdefg]	25.2 ± 6.9[abcdefg]
Recumbent Bike	17.1 ± 3.8[abcdefgh]	20.7 ± 5.2[abcdefg]	25.1 ± 6.1[abcdefg]
Arm Ergometer	11.5 ± 3.3[abcdefgi]	14.8 ± 4.0[abcdefghi]	18.2 ± 5.2[abcdefghi]

[a] Significantly lower than Treadmill ($p<0.05$).
[b] Significantly lower than Stair Stepper ($p< .05$).
[c] Significantly lower than AirDyne ($p< .05$).
[d] Significantly lower than Elliptical ($p< .05$).
[e] Significantly lower than Upright Bike ($p< .05$).
[f] Significantly lower than Cybex Arc Trainer ($p< .05$).
[g] Significantly lower than Rower ($p< .05$).
[h] Significantly lower than Recumbent Stepper ($p< .05$).
[i] Significantly lower than Recumbent Bike ($p< .05$).

Table 4. Energy expenditure (kcal/min) at RPE 11, 13, 15 on the 10 exercise machines (mean ± SD).

Machine	RPE11	RPE13	RPE15
Treadmill	9.3 ± 2.4	12.6 ± 2.9	14.4 ± 3.8
Stair Stepper	10.0 ± 2.3	11.8 ± 2.6	13.2 ± 2.8[a]
AirDyne	7.5 ± 1.9[abd]	9.3 ± 2.1[ab]	12.1 ± 3.0[a]
Elliptical	8.8 ± 1.6[b]	10.1 ± 2.3[ab]	11.7 ± 2.7[ab]
Upright Bike	8.2 ± 1.9[ab]	10.0 ± 2.5[ab]	11.8 ± 3.1[ab]
Cybex Arc Trainer	8.4 ± 1.0[ab]	9.8 ± 2.1[ab]	11.3 ± 2.7[ab]
Rower	7.6 ± 2.4[ab]	9.1 ± 2.8[ab]	11.1 ± 3.6[ab]
Recumbent Stepper	4.9 ± 1.6[abcdefg]	7.0 ± 2.1[abcdefg]	9.2 ± 2.8[abcdefg]
Recumbent Bike	6.2 ± 1.9[abcdefgh]	7.6 ± 2.5[abcdefg]	9.3 ± 2.9[abcdefg]
Arm Ergometer	4.2 ± 1.5[abcdefgi]	5.4 ± 1.8[abcdefghi]	6.7 ± 2.20[abcdefghi]

[a] Significantly lower than Treadmill ($p< .05$).
[b] Significantly lower than Stair Stepper ($p< .05$).
[c] Significantly lower than AirDyne ($p< .05$).
[d] Significantly lower than Elliptical ($p< .05$).
[e] Significantly lower than Upright Bike ($p< .05$).
[f] Significantly lower than Cybex Arc Trainer ($p< .05$).
[g] Significantly lower than Rower ($p< .05$).
[h] Significantly lower than Recumbent Stepper ($p< .05$).
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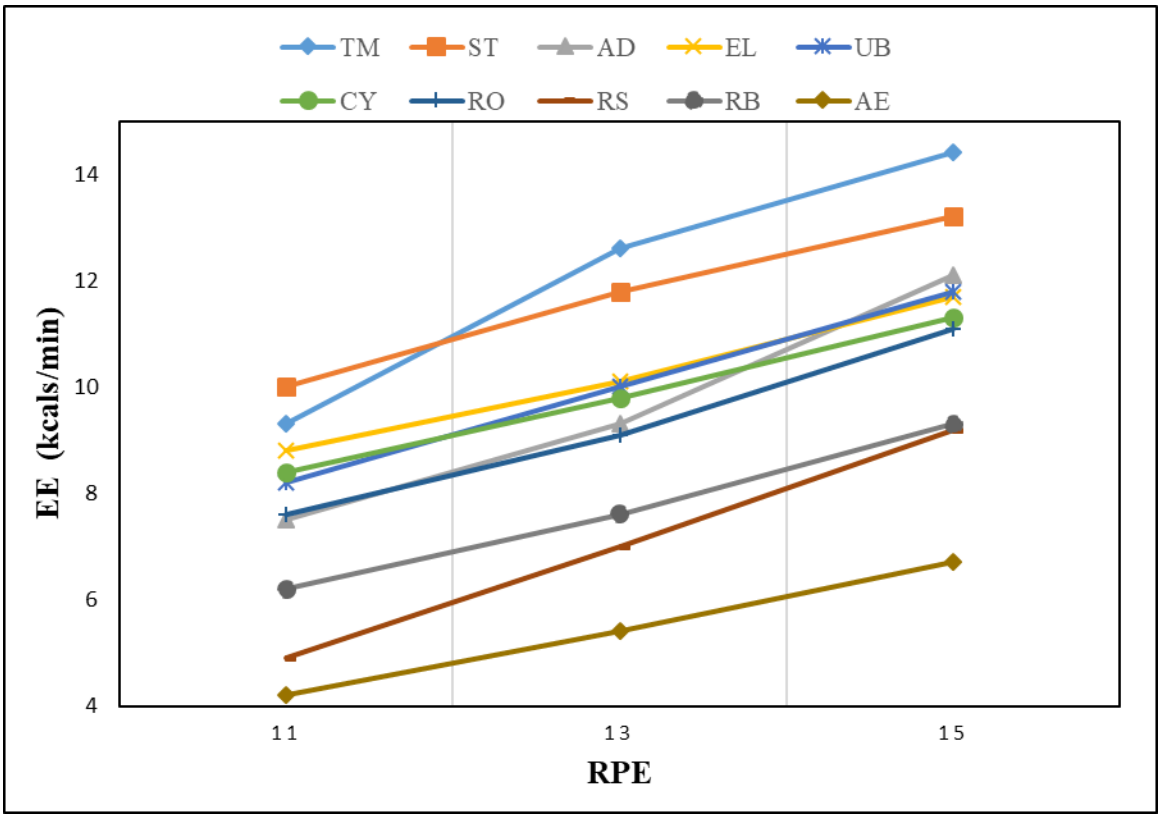

Figure 2. Energy expenditure (EE) (kcals/min) on the 10 exercise machines at RPE levels of 11, 13, and 15.

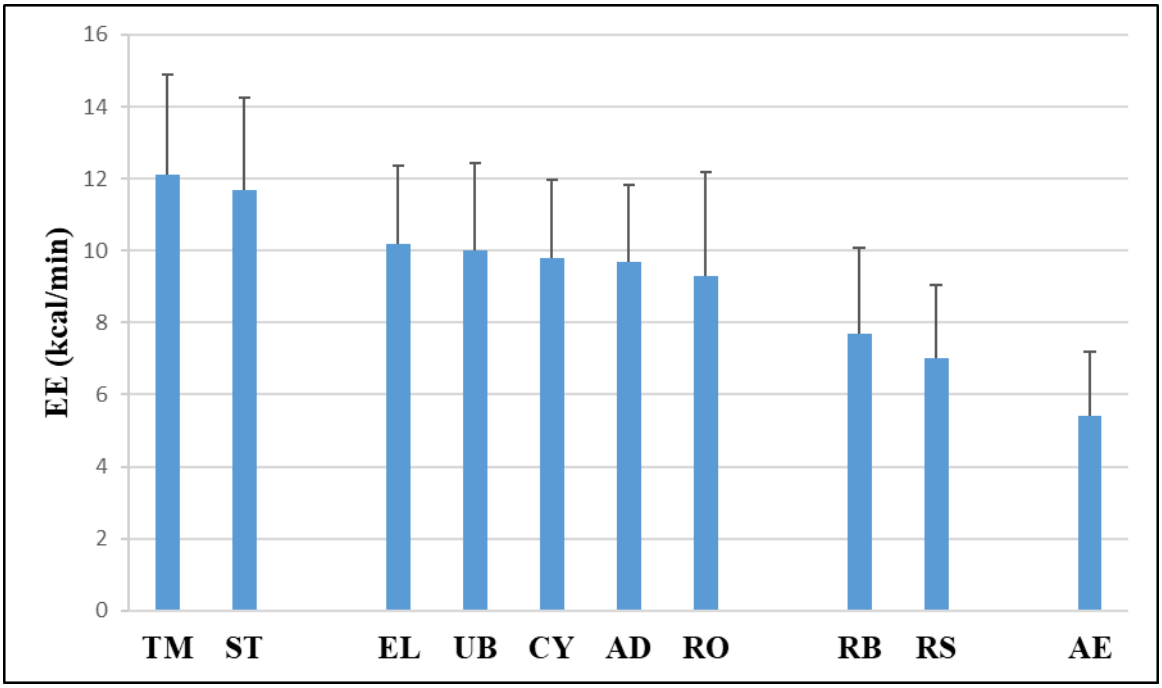

Figure 3. Energy expenditure (EE) (kcal/min) on the 10 exercise machines averaged across RPE levels.

Discussion

The main purpose of this study was to compare EE when exercising on 10 indoor exercise machines in an attempt to identify which one burns the most calories during exercise. Overall, TM and ST resulted in the highest EE compared to the other machines. The results for TM are in agreement with previous studies which identified the TM as eliciting the highest EE compared to a variety of other modalities[3,4,14-15]. The results for ST were somewhat surprising, as several of the abovementioned studies found that EE for ST was lower than TM exercise[3,4,14]. One explanation could be that all of the previous studies used a stepping machine, as opposed to a step mill, which was used in the current study. The step mill is essentially a continuous revolving staircase (like an escalator), and the user needs to fully lift their feet and legs against gravity with each step. With a stepping machine, the user's feet stay on the foot pedals, thus less external work is performed.

It was interesting to note that in the current study the overall EE for TM was greater than EL. This is in contrast to results of several studies. Brown et al.[5] and Porcari et al.[6] found that EE at a self-selected pace was similar between TM and EL exercise and both Dalleck et at.[7] and Egana and Donne[8] found that VO_2max determined on a TM and EL were similar. Our results could be the result of several factors. For example, Mier and Feito[16] found that at the same speed, metabolic demand increases as stride rate increases. In our investigation, we did not regulate stride rate for EL. Moreover, the incline when exercising on EL was higher than TM (which was level). This may have resulted in the participants using a slower stride rate on EL, which gave the muscles a greater time to rest.

The EE at all three RPE levels were similar for EL, UB, CY, AD, and RO. With the exception of UB, these modalities incorporated use of both the arms and legs. It has been shown previously that more work can be done at the same RPE when arm and leg work are combined[16]. It is also possible that subjects may have been more familiar with exercising on a stationary cycle (UB), since cycling is a common exercise modality. Even though subjects practiced exercising on the other machines, many of the machines involve new and relatively novel movement patterns. This may have resulted in a lower EE if subjects perceived them to be more difficult because they were less familiar with exercising on that modality. Similar to the current study, Turner et al.[17] also found no difference in EE during submaximal workouts on an arc trainer and an elliptical.

The EE on RB and RS was lower than all of the other modalities, except AE. When exercising on both RB and RS, the exerciser is in a recumbent position. Previous research has shown that there are significant cardiovascular differences when exercising in different postures[17-19]. Less muscular effort is required when performing exercise in a recumbent position, compared to an upright position, because of the back support afforded by the seat. The user can get a more efficient push against the resistance, resulting in lower EE.

Exercising on AE resulted in the lowest EE. This is in agreement with other studies and is attributed to the smaller muscle mass used during arm only exercise[20-21]. Since EE is a direct function of the amount of external work completed, and because the arms are relatively weaker than the legs, less

work was most likely performed during AE at the same perceived effort.

The results from previous studies that compared RO and UB were quite different than the results of the current study. Most studies have found that RO results in a significantly higher EE compared to UB during submaximal exercise[3,4,10-12]. However, Bouckaert et al.[10] found that non-rowing professionals had a lower VO_2 on RO than UB during maximal exercise. In our investigation, we found that there was no significant difference between RO and UB at all three RPE levels. None of our subjects were trained rowers, which probably explains the non-significant differences between RO and UB.

In order to put the EE results into perspective, Table 5 was developed based upon the EE at RPE 13. RPE 13 corresponds to a moderate intensity workout[2], and is in line with the intensity individuals work at when asked to exercise at a self-selected pace[5-6]. The EE data were extrapolated to 1) determine how many calories would be expended in 30 minutes when exercising on each machine, and 2) determine how long it would take to expend 300 calories. It is recommended that individuals expend 1200-2000 kcal per week (240-400 kcal per exercise session) in order to positively impact body composition[22], and expending 300 calories per exercise session is a common goal. As can be seen in Table 5, there is tremendous variability in EE depending upon exercise machine. For instance, on the arm ergometer, a person only burns 43% as many calories as exercising on the treadmill, and it would take more than twice as long to burn 300 calories.

Table 5. Energy expenditure in 30 minutes of exercise on each machine and how long it would take to expend a total of 300 kcal.

	Energy Expenditure 30 minutes	Time to Expend 300 kcal (min:sec)
Treadmill	378	23:47
Stepper	354	25:25
Elliptical	303	29:42
Upright Bike	300	30:00
Cybex Arc Trainer	294	30:04
AirDyne	279	32:16
Rower	273	32:58
Recumbent Bike	228	39:29
Recumbent Stepper	210	42:52
Arm Ergometer	162	55:34

Even though the TM and ST resulted in the highest overall EE, it should be noted that there are potential benefits of every exercise machine tested in the current study. For instance, using a treadmill does not involve the upper body musculature. If someone's goal is get a total body

workout, a machine such as the AD that simultaneously exercises the arms and legs would be beneficial. Individuals with orthopedic issues in the lower extremities might not be able to walk or run on a treadmill or might not be able to use a step mill. They could benefit from a machine such as the RS, UB, RB, or EL that provides a lower impact exercise option. Porcari et al.[6] found that exercising on an elliptical trainer that simultaneously used the arms and legs provided a similar intensity workout as running on a treadmill, but the impact forces were similar to walking. One other factor to consider when prescribing exercise is exercise enjoyment. Exercising on the same machine day after day can get boring. Having a variety of options may contribute to better exercise enjoyment and long-term adherence.

A limitation of this study was that data were collected only on healthy, young students who were regular exercises. In addition, the exercise intensities were based on a subjective rating scale (e.g., RPE). It is possible that these physiological responses may not be in line with perceptions of individuals who are physically inactive, less fit, or have medical conditions. Even though subjects practiced each modality 3-5 times, and were deemed proficient on each machine by the research staff, it is possible that they were more familiar and comfortable with some modalities versus others. This may have resulted in a lower EE on those machines with which they were less familiar.

Conclusions

Based upon the results of our study, the best indoor exercises machine to maximize EE are the TM and ST for healthy young adults. However, it should be kept in mind that the other exercise machines are viable options for individuals who have orthopedic issues or want to train specific muscles.

Disclosures

This study was funded by the American Council on Exercise (ACE). However, ACE was not involved in the design of this study, collection or analysis of the data, or the preparation of this manuscript.

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