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A COMPARISON OF THE PHYSIOLOGICAL RESPONSES TO EXERCISE ON TEN AEROBIC EXERCISE MODALITIES

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A Comparison of the Physiological Responses to Exercise on Ten Aerobic Exercise Modalities

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

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ABSTRACT

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The purpose of this study was to compare the cardiopulmonary responses on 10 exercise modalities. Sixteen subjects (8 males and 8 females) completed exercise tests on a treadmill (TM), stepper (ST), airdyne (AD), elliptical (EL), upright bike (UB), cybex arc trainer (CY), rower (RO), recumbent stepper (RS), recumbent bike (RB), and arm ergometer(AE). Self-selected workloads that elicited RPE levels of 11, 13, and 15 on the 6-20 Borg scale were used on each modality. Heart rate (HR) and oxygen consumption (VO_2) were measured, and used to calculate oxygen pulses (VO_2pulse). TM and ST exercise elicited the highest HRs, and were significantly higher than AD, RO, RS, RB, and AE. TM and ST had the highest VO_2, followed by AD, EL, UB, CY, RO, RS, RB, and AE. AD, EL, UB, CY, and RO were significantly higher than RS, RB, and AE. There were no significant differences in O_2pulse between TM, ST, AD, EL, and RO while AE had the lowest value. It was concluded that the best aerobic exercises are the TM and ST.

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INTRODUCTION

The incidence of cardiovascular disease, obesity and, other significant health issues has increased significantly in recent years. It is also well known that regular physical activity, especially aerobic exercise, reduces cardiac risk factors and can help to maintain or improve cardiopulmonary fitness (ACSM, 2017). There are a growing number of individuals using aerobic exercise machines at home or in rehabilitation facilities. Many people are limited by how much time they have for exercise. Thus, identifying the most efficient exercise machine could be beneficial for medical practitioners and the general public.

Energy expenditure (EE) in a given amount of time is arguably the best way to determine the most efficient exercise machine. Over the years, a number of studies have compared the EE of exercise on different exercise modalities. Oxygen pulse (O_2pulse) is another way to quantify exercise efficiency. O_2pulse is calculated by dividing oxygen consumption (VO_2) by heart rate (HR). The most efficient exercise delivers the highest amount of oxygen per heartbeat (mL O_2/beat).

Numerous studies have found that exercising on a treadmill or an elliptical machine expends a similar number of calories. For instance, Dalleck, Kravitz and Robergs (2004) studied the physiological responses during incremental exercise tests on a treadmill and elliptical. They found that the treadmill and elliptical produced similar VO_2max values. Similarly, Egana and Donne (2004) found that VO_2max values on the treadmill, elliptical, and stair climber were not significantly different from one another. Brown, Cook, Krueger, and Heelan (2010) measured EE and VO_2 during two 15-minute submaximal exercise tests on a treadmill and an elliptical. There was no significant difference in EE or VO_2 during the treadmill and elliptical exercise tests.

The treadmill is often considered to be the most energy demanding exercise machine, followed by stair climbing, rowing, and cycling. Zeni, Hoffman and Clifford (1996) measured EE at an RPE of 11, 13, and 15 when subjects exercise on treadmill, airdyne, cross-country skiing machine, cycle ergometer, rowing ergometer, and stair stepping machine. They found that the treadmill produced the highest EE compared to the other modalities. They concluded that the treadmill is the best indoor exercise machine for EE when RPE is used to guide exercise intensity. Moyna et al. (2001) also 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 ski simulator in men, while in women the highest EE was measured on the treadmill, ski simulator, and rowing ergometer.

A study conducted by Hill, Oxford, Duncan and Price (2015) compared VO_2 during an incremental exercise test on a treadmill, cycle ergometer, and an arm ergometer. They found that VO_2 was greater on the treadmill when compared to both the arm and cycle ergometer. It was concluded that exercising on the treadmill expends the greatest number of calories compared to cycling and arm ergometers. This is most likely due to the fact that both cycling and arm ergometry are non-weight bearing exercises and utilize a smaller muscle mass.

In a previous study conducted by Bouckaert, Pannier, and Vrijens (1983), EE was measured using a cycle ergometer and a rowing machine. Oxygen consumption and maximal O_2pulse were measured during a maximal exercise test on each modality. Results of the study found that the rowing machine produced lower VO_2max and maximal O_2pulse values when compared to the cycle ergometer. Similar to the above mentioned study, Mahler, Andrea, and Ward (1987) found that VO_2max was significantly greater on the cycle ergometer when compared to the rowing machine. Conversely, research presented by Hagerman, Lawrence, and Mansfield (1988) concluded that EE on the rowing machine was significantly higher than the cycle ergometer.

Due to the conflicting data presented above, the purpose of this study was to compare HR, VO_2, O_2pulse and EE among 10 different exercise modalities in an attempt to identify the" best" exercise machine. The 10 machines compared were the treadmill (TM), stair stepper (ST), airdyne (AD), elliptical (EL), upright bike (UB), cybex arc trainer (CY), rower (RO), recumbent stepper (RS), recumbent bike (RB), and arm ergometer (AE).

METHODS

Subjects

Eight apparently healthy males and eight apparently healthy females between 18-25 years of age participated in this study. The study was approved by the Institutional Review Board-for the Protection of Human Subjects prior to any data collection. All subjects provided written informed consent before undergoing any testing or training procedure. Subjects were screened with the PAR-Q and those individuals with known cardiovascular, metabolic, or pulmonary disease, and any musculoskeletal disorders were excluded from participation.

Procedures

Each subject performed 3-5 practice sessions on each of the 10 exercise machines. The 10 exercise modalities include a motorized Matrix treadmill (TM) (Taiwan), Life Fitness power mill stepper (ST) (Madison, WI) , Schwinn airdyne (AD), Matrix elliptical (EL) (Taiwan), Monarch upright bike (UB) (Vansbro, Sweden), Cybex arc trainer (CY) (Rosemont, IL), Concept 2 rower (RO) (Morrisville, VT), Scifit Step One recumbent stepper (RS) model Sone (Tulsa, OK) Precor recumbent bike (RB) (Woodinville, WA), and Scifit Pro 2 arm ergometer (AE) (Tulsa, OK). Prior to exercising, each subject received standard instructions on the use of the 6-20 Borg RPE scale (Borg, 1982). During the practice sessions, subjects self-selected workloads that elicited RPE levels of

11, 13, and 15, which correspond to the verbal anchor points of “light”, “somewhat hard”, and “hard” on the 6-20 Borg scale.

Each subject then completed five testing sessions that were conducted on separate days, with a minimum of 48 hours between testing days. Each session consisted of two exercising modalities selected in random order. On each modality, subjects warmed-up for 3 minutes at 75% of the work rate correlating to an RPE 11. They then performed a 5-minute bout at an RPE of 11, a 5-minute bout at an RPE of 13, and exercised for 5-minutes at an RPE of 15. Subjects performed a cool-down for 3 minutes at the same level of intensity as the warm-up. During the first 3 minutes of each stage, subjects were able to adjust the workloads so the intensity would correspond to the elicited RPE levels. Subjects then rested for 15 minutes and repeated the exercise sequence on the second modality.

During each stage of exercise, HR was recorded each minute using a Polar HR watch (Polar Electro Oy, Kempele, Finland), VO_2 was continuously measured using an Oxygen Mobile ™ (CareFusion, Yorba Lina, Ca) portable calorimetric measurement system. This system was calibrated 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 the manufacture guidelines. Calibration of the pneumotachometer was done via a 3 liter calibration syringe (Hans-Rudolph, Kansas City, MO). RPEs were assessed at the end of each stage using the 6-20 Borg scale. EE was calculated from the VO_2 data assuming a constant of 5 kcal for each liter of O_2 consumed (5 kcal/L) and O_2pulse (mL O_2/beat) was calculated from the VO_2 and HR data.

Statistical Analysis

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 O_2pulse between modalities and RPE levels. There was a significant main effect for modality, and there was also a significant interaction. Thus, comparisons of the physiological responses between the 10 modalities at each RPE level were made using one-way ANOVA with repeated measures. If there was a significant F-ratio, difference between specific modalities 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.

RESULTS

Descriptive characteristics of the 16 subjects who participated in the study are presented in Table 1. The HR responses to exercise on the 10 modalities at each RPE level are presented in Table 2 and Figure 1, respectively.

Table 1. Selected characteristics of the subjects.

	Male (n=8)	Female (n=8)
Age, y	22.4 ± 0.92	22.0 ± 1.60
Height, cm	179.8 ± 4.09	165.1 ± 8.64
Weight, kg	82.6 ± 6.23	64.0 ± 7.89
BMI	25.5 ± 1.44	23.6 ± 3.20

Values represent mean ± standard deviation.

There were significant differences in HR among modalities, with mean values varying by up to 46 beats per minute. TM and ST exercise elicited the highest HR at each RPE, and these values were significantly higher than AD, RO, RS, RB, and AE at all three RPE levels. Heart rates for TM and ST were also significantly higher than EL at RPE 13 and 15, but only ST was significantly higher at RPE 11. There was no significant difference between EL and CY, however, EL had significantly higher HR compared to RO, RS, RB, and AE, except for RO at RPE 15. CY, UB and RO had significant higher HR compared to RS, RB, and AE.

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

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[ab]	137 ± 17.1[ab]	160 ± 14.0[ab]
Elliptical	133 ± 16.2[c]	145 ± 13.7[ab]	159 ± 12.0[ab]
Upright Bike	129 ± 14.6[b]	147 ± 15.8[ab]	161 ± 14.7[b]
Cybex Arc Trainer	138 ± 21.5[c]	150 ± 19.0[bc]	161 ± 17.4[ab]
Rower	118 ± 12.4[abdf]	132 ± 13.5[abdef]	148 ± 16.5[abcef]
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]

Values represent mean ± standard deviation.
[a] Significantly different from Treadmill ($p < .05$).
[b] Significantly different from Stair Stepper ($p < .05$).
[c] Significantly different from Airdyne ($p < .05$).
[d] Significantly different from Elliptical ($p < .05$).
[e] Significantly different from Upright Bike ($p < .05$).
[f] Significantly different from Cybex Arc Trainer ($p < .05$).
[g] Significantly different from Rower ($p < .05$).
[h] Significantly different from Recumbent Stepper ($p < .05$).
[i] Significantly different from Recumbent Bike ($p < .05$).

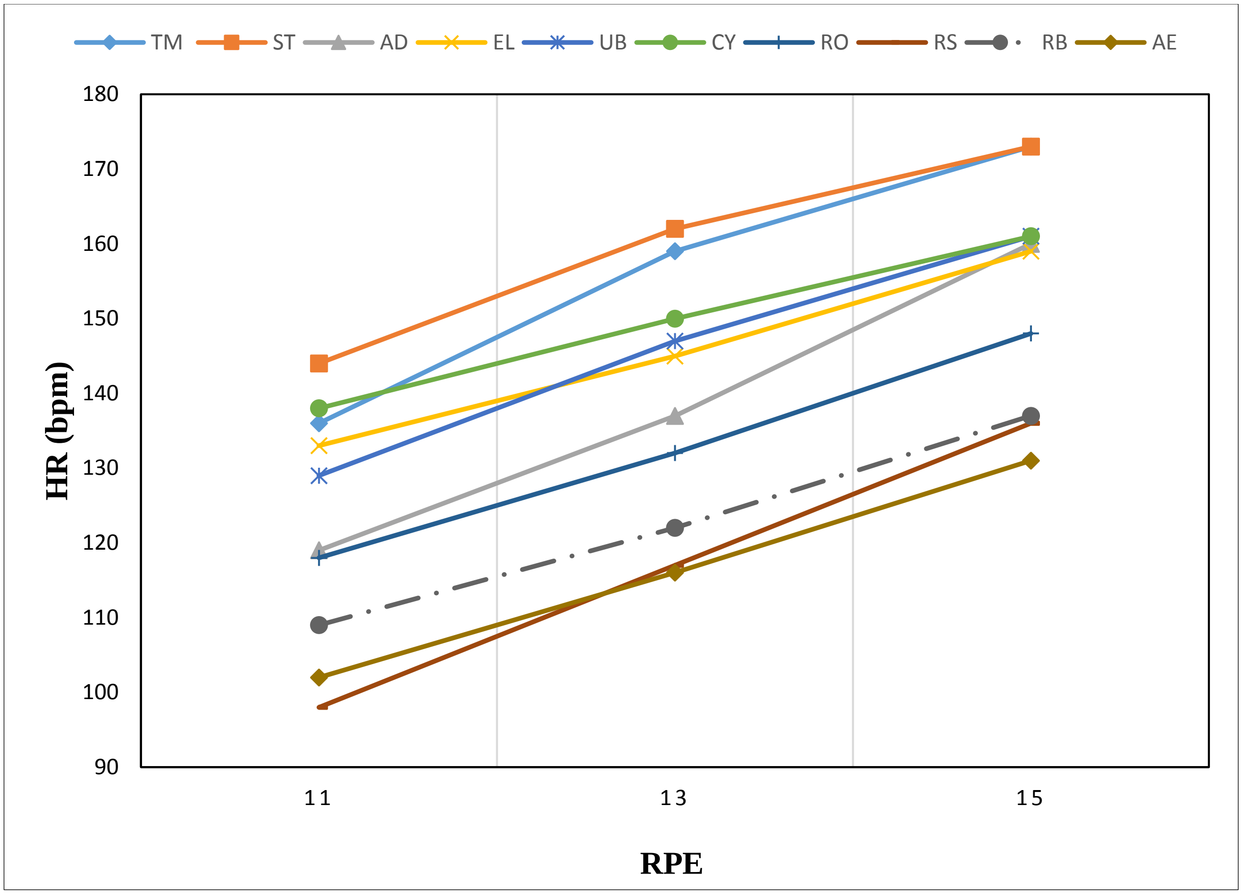

Figure 1. Heart rate (bpm) on the 10 different modalities at RPE levels of 11, 13, and 15.

The VO_2 responses to exercise are presented in Table 3 and Figure 2, respectively. TM had the highest VO_2 compared with the other machines at RPE 15, followed by ST, AD, EL, UB, CY, RO, RS, RB, and AE. Except for ST, VO_2 for TM was significantly greater than the other eight machines. AD, EL, UB, CY, and RO were significantly higher compared with RS, RB, and AE. The results were similar at RPE 11 and 13.

Table 3. VO_2 (ml/kg/min) response at RPE 11, 13, and 15 on the 10 different exercise machines.

Machine	RPE11	RPE13	RPE15
Treadmill	26.3 ± 6.82	34.5 ± 5.96	39.0 ± 7.43
Stair Stepper	27.5 ± 3.92	32.3 ± 4.15	35.8 ± 4.80
Airdyne	21.0 ± 3.44[ab]	25.8 ± 4.70[ab]	33.2 ± 5.93[a]
Elliptical	24.6 ± 4.20[c]	28.2 ± 5.28[ab]	32.1 ± 5.78[ab]
Upright Bike	22.5 ± 4.13[ab]	27.1 ± 5.19[ab]	31.7 ± 5.95[ab]
Cybex	23.6 ± 4.71[b]	27.2 ± 5.34[ab]	31.1 ± 6.57[ab]
Rower	23.6 ± 4.71[abd]	25.2 ± 6.09[abd]	30.2 ± 8.20[ab]
Recumbent Stepper	13.6 ± 3.93[abcdefg]	19.4 ± 4.75[abcdefg]	25.2 ± 6.86[abcdefg]
Recumbent Bike	17.1 ± 3.83[abcdefgh]	20.7 ± 5.18[abcdefg]	25.1 ± 6.14[abcdefg]
Arm Ergometer	11.5 ± 3.26[abcdefgi]	14.8 ± 4.03[abcdefghi]	18.2 ± 5.22[abcdefghi]

Values represent means ± standard deviation
[a] Significantly different from Treadmill ($p<0.05$).
[b] Significantly different from Stair Stepper ($p< .05$).
[c] Significantly different from Airdyne ($p< .05$).
[d] Significantly different from Elliptical ($p< .05$).
[e] Significantly different from Upright Bike ($p< .05$).
[f] Significantly different from Cybex Arc Trainer ($p< .05$).
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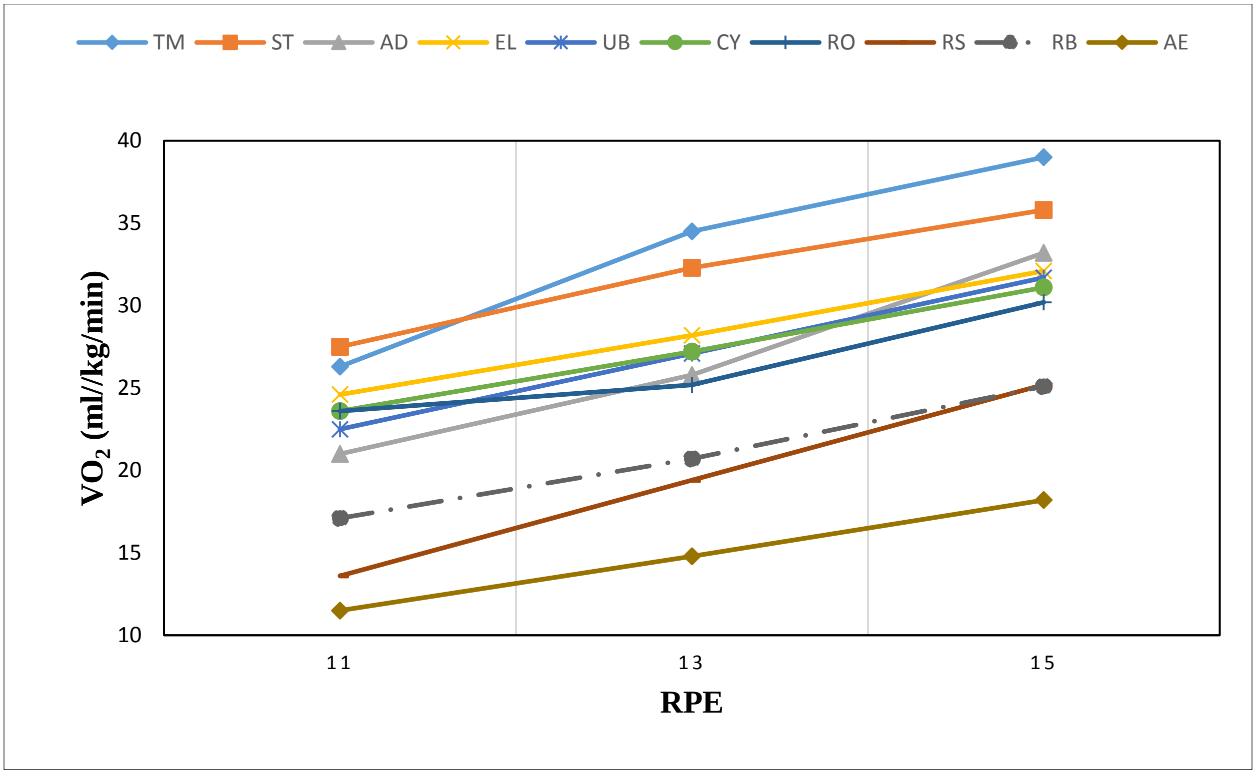

Figure 2. Oxygen uptake (ml/kg/min) on the 10 exercise modalities at RPE levels of 11, 13, and 15.

Data for O_2pulse are presented Table 4 and Figure 3, respectively. There were no significant differences in O_2pulse between TM, ST, AD, EL, and RO at all three RPE levels. UB and CY were significantly lower than TM at RPE 15. AE had the lowest O_2pulse values among the 10 machines and was significantly lower than all the other machines at RPE 11 and 15, and significantly lower than all other modalities except the RB at RPE 13.

Table 4. Oxygen Pulse (ml/beat) response at RPE 11, 13, and 15 on the 10 different exercise machines.

Machine	RPE11	RPE13	RPE15
Treadmill	14.2 ± 3.82	15.5 ± 5.66	16.7 ± 4.86
Stair Stepper	14.3 ± 3.72	14.8 ± 3.78	15.4 ± 3.96
Airdyne	13.1 ± 3.52	14.0 ± 4.06	15.4 ± 4.47
Elliptical	13.8 ± 3.66	14.3 ± 4.16	15.1 ± 4.29
Upright Bike	13.0 ± 3.60	13.7 ± 3.90	14.6 ± 4.18[a]
Cybex Arc Trainer	12.8 ± 3.56	13.5 ± 3.61	14.4 ± 3.96[a]
Rower	13.2 ± 4.28	14.1 ± 4.39	15.0 ± 4.92
Recumbent Stepper	10.4 ± 3.49[abcdefg]	12.3 ± 3.69[a]	13.6 ± 3.75[a]
Recumbent Bike	11.8 ± 3.82[abd]	12.7 ± 4.19	13.6 ± 4.19[a]
Arm Ergometer	8.5 ± 3.22[abcdefghi]	9.6 ± 3.43[abcdefg]	10.3 ± 3.50[abcdefghi]

Values represent mean ± standard deviation.
[a] Significantly different from Treadmill ($p < .05$).
[b] Significantly different from Stair Stepper ($p < .05$).
[c] Significantly different from Airdyne ($p < .05$).
[d] Significantly different from Elliptical ($p < .05$).
[e] Significantly different from Upright Bike ($p < .05$).
[f] Significantly different from Cybex Arc Trainer ($p < .05$).
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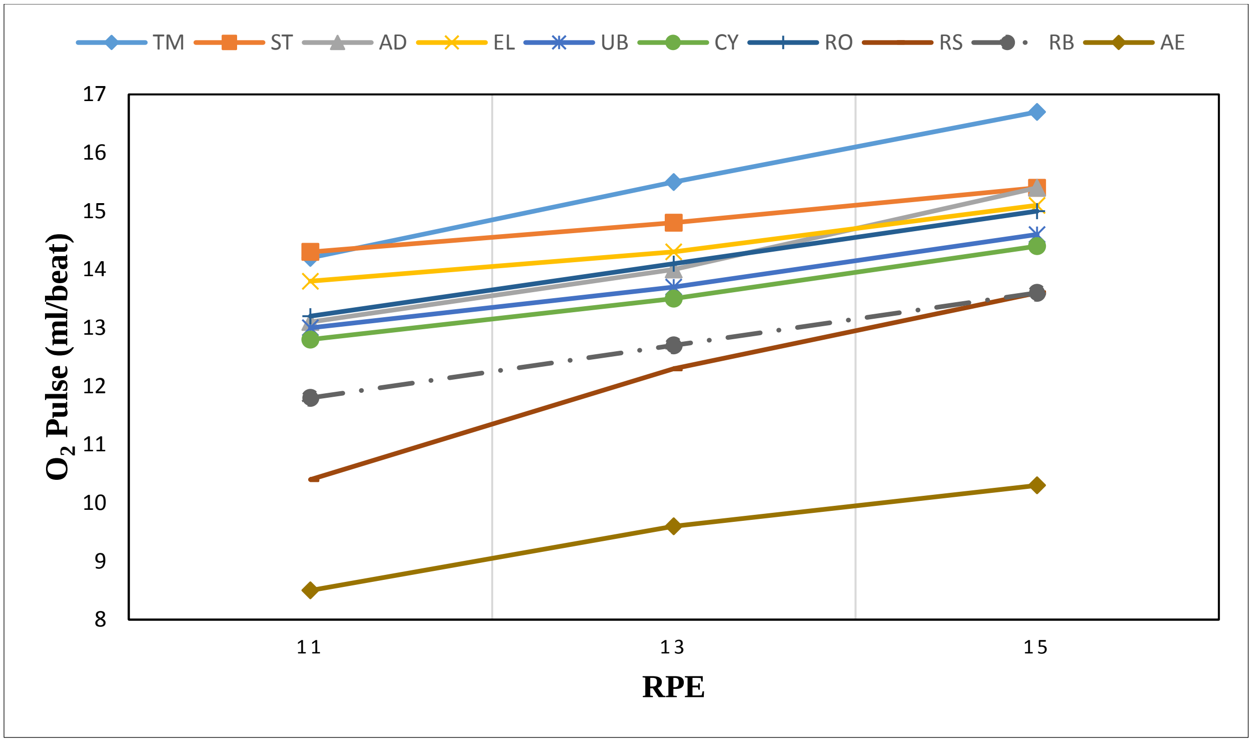

Figure 3. Oxygen pulse (ml/beat) on the 10 different exercise machines at RPE levels of 11, 13, and 15.

The average values for O_2pulse, collapsed across all three RPE levels for the different machines, are presented in Figure 4. The results generally fell into four groupings. TM and ST had the highest O_2pulse, followed by EL, AD, RO, UB, and CY. The two recumbent exercise modalities, RB and RS, fell into the next group, with the O_2pulse for AE being the lowest among of all the exercise modalities.

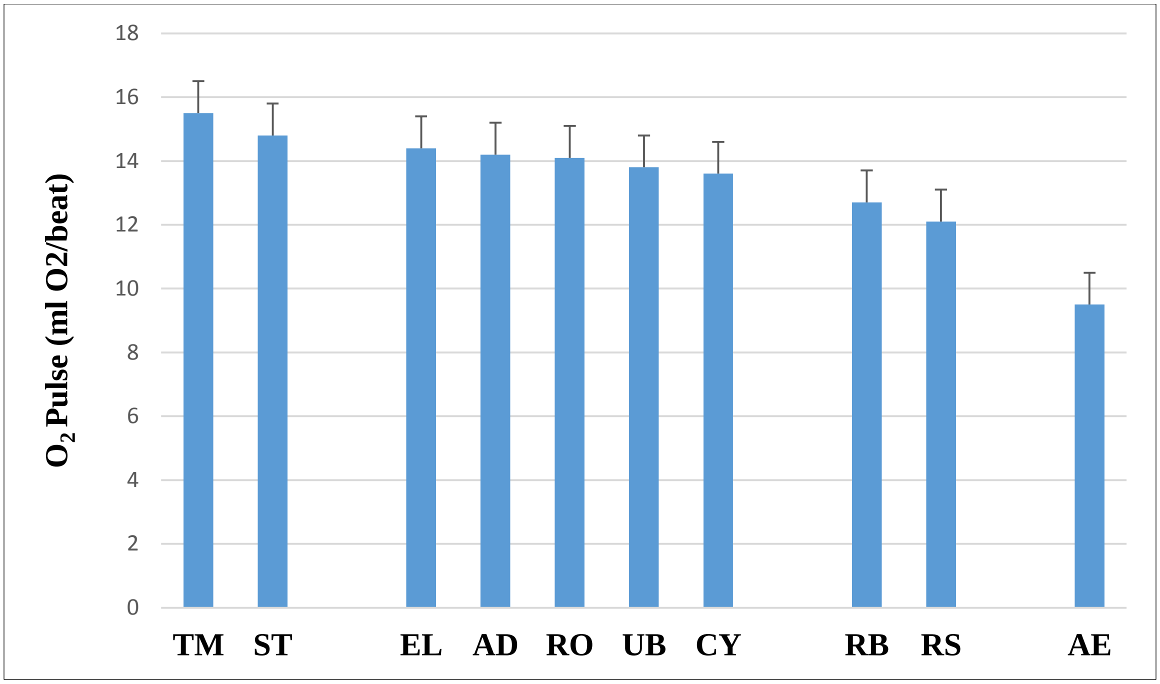

Figure 4. Oxygen pulse (ml/beat) on the 10 different exercise machines.

DISCUSSION

To my knowledge, this is the first study to compare a total of 10 different exercise modalities. Previous investigations had compared six modalities (Mona et al. 2001; Zeni et al. 1996; Thomas, Ziogas, Smith, Zhang, & Londeree, 1995) and four modalities (Kravitz, Robergs, Heyward, Wagner & Powers, 1997). This study found that there are considerable differences in the physiological responses among TM, ST, AD, EL, UB, CY, RO, RS, RB, and AE during exercise.

Generally, the difference in physiological responses at each given RPE among these 10 modalities could be explained by the amount of muscle mass utilized during exercise. Several other reports (Sargeant & Davies, 1973; Ekblom & Goldbarg, 1971) have also shown that the amount of exercising muscle influences the relationship between metabolic demand and RPE.

Oxygen Consumption Responses

TM exercise is the most widely used modality in the medical and fitness fields and is commonly believed to require the most VO_2 compared to other aerobic exercise machines. Our findings are in agreement with this, as TM elicited a significantly higher VO_2 than the other modalities. However, we found there was no significant difference in VO_2 between TM and ST at each RPE. VO_2 for ST was even slightly higher than TM at

RPE 11. Other studies (Mona et al., 2001; Zeni et al., 1996; Kravitz et al., 1997; Thomas et al., 1995) that compared multiple machines also reported that exercising on a TM had the highest VO_2 compared to working on a ski simulator, rower, stair climber, and cycle at the same perceived effort. Different results regarding the VO_2 for TM and ST were noted in these two studies. The conflicting results may be due to the different protocols used. Zeni et al. (1996) measured the physiological responses from lower intensity to higher intensity exercise (e.g., RPE 11, 13, and 15) which is similar to our protocol. However, the participants from their study took a 2-minute break between each RPE level. The rest in between workloads probably decreased muscle fatigue, since the continuous stepping is considered an isometric contraction on the lower limbs. Similarly, subjects from the study by Moyna et al. (2001) took an even longer rest time between each exercise intensity (15 minutes rest) and performed 6 minutes at each RPE. In contrast, in our study participants experienced a sequence of 21 minutes of continuous climbing on the stair stepper which could have led to the higher metabolic demand.

Previous investigations (Brown et al., 2010; Dalleck et al., 2004; Egana & Donne, 2004) which compared the physiologic responses during exercise on TM and EL found that there was no significant differences in VO_2 between these two modalities. Our findings differ from other studies when comparing VO_2 between TM and EL. Our study found that VO_2 demand on TM was significantly higher than EL. Although TM and EL are both considered full body exercises, it is logical to assume that they would have a similar metabolic responses at the same perceived exertion. These results could be influenced by several factors. For example, the VO_2 demands may be different if the stride rates were not equivalent. It has been shown that at the same speed, the metabolic demand increases as the stride rate increases (Mier & Feito, 2006). In our investigation, we did not regulate the stride rate for EL. Moreover, the incline from EL was higher than TM (level). This may have resulted in the participants using a slower stride rate on the EL and gave more time for the muscles to rest.

Similar findings were seen on the CY. CY and EL are designed for people who suffer from low back, hip, knee or lower limb pain. Both modalities provide a low impact workout and provide a safer exercise opportunity for a broader population. We found that there was no significant difference between EL and CY, despite EL producing slightly higher VO_2 at each RPE. Our results are in agreement with those of Turner, Williams, Williford, and Cordova. (2010), who also reported that exercise on a TM used more oxygen than EL and CY.

AD, UB, RO, RS, RB and AE are all considered non weight-bearing exercise modalities. Logically, the metabolic responses should had been lower than TM and ST (Zeni et al., 1996; Moyna et al., 2001; Kravitz et al., 1997; Thomas et al., 1995). But, non-weight bearing exercise is suitable for people who are at risk of falls, or during lower body rehabilitation. VO_2 was not significantly different among AD, UB, and RO. However, the above three modalities elicited significantly higher VO_2 responses compared to RS, RB, and AE. VO_2 during AE was significantly lower compared to the other modalities. In fact, AE was the least metabolic demanding exercise among these 10 exercise modes, mainly because it uses the smallest muscle mass during exercise. Several other studies (Eston & Brodie, 1986; Nagle, Richie & Giese, 1984) also reported that VO_2 was lower during AE compared to leg cycling.

The results from previous studies that compared RO and UB were quite different than the current study (Hagerman et al., 1988, Mahler et al., 1987; Bouckaert et al., 1983; Zeni et al., 1996; Moyna et al., 2001). The common results from most studies shows that RO produced a significantly higher physiological response than UB during submaximal exercise. However, Bouckaert et al. (1983) found that non-rowing professionals had 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, which was in agreement with the study by Moyna et al. (2001). All subjects in our study were not trained rowers, which probably explains the non-significant differences between RO and UB.

Heart Rate Responses

Although many studies compared the cardiopulmonary response on multimodalities exercise, the majority of investigations only focus on VO_2 or EE. Very few studies focused on HR. In general, weight bearing exercise modalities elicited higher HR compared to non-weight bearing movements. These results are in agreement with previous investigations from other researchers (Moyna et al., 2001; Zeni et al., 1996; Kravitz et al., 1997; Thomas et al., 1995). The highest HR were found for TM and ST, and the lowest exercise HR was found for AE.

I did not expect ST to have the highest HR response, even though it was not significantly higher than TM. Previous investigations (Zeni et al. 1996; Moyna et al. 2001; Thomas et al. 1995) reported that the HR response was lower on ST than TM. Again, the different results between studies may be due to the different protocols used.

Although the exercise intensities were similar among the three studies, the other protocols included 2, 15, and 20 minutes of resting or recovery time between each exercise level (RPE 11, 13, and 15).

One reason which may explain why ST had a higher HR compared to TM is the pressor response (Porcari, 1996). For an aerobic exercise, HR increases proportionally relative to VO_2 in order to meet the metabolic demands of the muscles. With ST, the continuous stair climbing is similar to a resistance training-like environment. Thus, the muscles are working at a higher percentage of their maximal strength. This would elevate HR disproportionally higher relative to VO_2.

Similar to the current study, the investigation by Zeni et al. (1996) found that HR during TM was significantly greater than AD, UB and RO. Moreover, Moyna et al. (2001) and Thomas et al. (1995) found similar results for exercise HR responses. They both found that HR on the TM was higher than UB and RO.

I found that there were no significant differences between AD and UB despite the fact that AD utilizes the arms and legs during exercise. The two similar exercise motions, EL and CY, also showed similar HR responses. RS, RB, and AE all had significantly lower HR than the other seven modalities. The lower HR for RS and RB was most likely due to the fact that both exercises are performed in the recumbent position. This facilitates venous return, which would result in a lower HR at any given cardiac output because of an enhanced Frank-Starling mechanism.

Oxygen Pulse Responses

O_2pulse is arguably the best way to evaluate which is the “best” exercise machine. It is a measure of how much oxygen is delivered per heartbeat. O_2pulse was the highest during running on the TM. ST had the second highest O_2pulse, and it was very close to the values of AD, EL, and RO. UB and CY showed slightly lower O_2pulse at fairly light and somewhat hard exercise intensity, but they both displayed significantly lower values at the highest intensity. Our findings are in agreement with those of Thomas et al. (1995). They also found TM to have the highest O_2pulse followed by ST, AD, RO and UB.

The oxygen volume delivered per heart beat to the target tissue is considered an indicator of stroke volume (SV) (Astrand & Rodahl, 1986). During aerobic exercise, HR and VO_2 increase during incremental exercise. The more VO_2 delivered per heart beat is a sign of efficiency. On the other hand, a disproportionate increase in HR relative to VO_2 indicates that the body is not working as aerobically. This phenomenon is usually seen during resistance training (Hurley et al.1984). The intramuscular pressure elevates the afterload against which the left ventricular must contract. Thus, SV from each heart beat is lower. In order to compensate for the reduced SV, HR must increase to maintain cardiac output.

In our investigation, AE had the lowest O_2pulse of all of the exercise modalities. This was most likely due to the small muscle mass used during the exercise motion. Similar findings were reported by Lewis et al. (1983). They found that HR was higher with the use of a smaller muscle mass, in relation to VO_2. In fact, the SV from arm-cranking was significantly lower than leg cycling. On the contrary, traditional aerobic exercise such as TM, ST, AD, EL, RO, and UB were all considered good aerobic exercise modalities during moderate intensity exercise.

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 scales (e.g., RPE). It is possible that these physiological responses may not be in line with that of people who are sedentary, less fit, or have medical conditions.

CONCLUSION

Base upon the results of our study, the best aerobic exercises are TM running and ST climbing for healthy young adults. Weight bearing exercise modalities seem to be more aerobically efficient than non-weight bearing modalities. Additionally, EL, CY, AD and UB were slightly less efficient than TM and ST, but are good alternative exercise modalities. Although RS, RB, and AE required less cardiopulmonary response, they are still good exercise modalities for specific populations who have orthopedic issues or want to train specific muscles.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

Relative Exercise Intensity of Exercising on Different Cardio Machines at Matched Levels of Perceived Exertion

I,______________________________, volunteer to participate in a research study being conducted at the University of Wisconsin-La Crosse.

Purpose and Procedures

- The purpose of this study is to determine the physiological responses to exercising on 8-10 different cardio machines (e.g., motorized treadmill, elliptical trainer, stepmill, recumbent cycle, upright cycle, NuStep, arm ergometer, rower).
- Research assistants will be conducting the research under the direction of Dr. John P. Porcari, a Professor in the Department of Exercise and Sport Science.
- My participation in this study will involve completing a minimum of 3, 15-minute practice sessions on each machine.
- Once I am deemed proficient on each machine by the study staff, I will complete 1, 15-minute bout of exercise on each machine. This workout will consist of sequentially completing 5 minutes of exercise at 3 different workloads that I subjectively deem to be fairly light, somewhat hard, and hard. During these workouts I will wear a chest strap to measure my heart rate and breathe through a scuba-type mouthpiece to analyze my expired air.
- Total time commitment for this study will be approximately 20 hours, depending upon how many practice sessions I need to complete.

Potential Risks

- I may experience overall muscle fatigue and muscle soreness as a result of completing the workouts required in the current study. Additionally, shortness of breath, irregularities in heart rhythm, heart attack, stroke, and death are always possible consequences of exercise. However, the risk of serious or life-threatening complications is very low (<1/10,000 tests) in apparently healthy adults.
- The test will be stopped immediately if there are any complications.
- Individual trained in Cardiopulmonary Resuscitation (CPR) and Advanced Cardiac Life Support (ACLS) will be available during all testing sessions. In addition, an Automatic External Defibrillator (AED) is available in the laboratory where testing will take place.

Benefits

- Because of the number of workouts I will be completing, I may experience an improvement in my fitness level.
- I will be paid $50 if I complete the entire practice and testing protocol.

Rights and Confidentiality

- My participation is voluntary.
- I may choose to discontinue my involvement in the study at any time, for any reason, without penalty.
- The results of this study have the potential of being published or presented at scientific meetings, but my personal information will be kept confidential and only group data will be presented.

I have read the information provided on this consent form. I have been informed of the purpose of this study, the procedures, and the expectations of myself and the testers, and of the potential risks and benefits that may be associated with volunteering in this study. I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

If I have any other questions that arise I may feel free to contact John Porcari, the principal investigator, at (608) 785-8684. Questions in regards to the protection of human subjects may be addressed to the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects at (608)785-8124.

Subject:________________________________ Date: __________________

Investigator:____________________________ Date: __________________

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The purpose of this literature review is to discuss the physiological responses on different kinds of aerobic exercise machines. The second purpose of the review is to provide a general concept of aerobic machine efficiency for cardiologists and health professionals to implement into their practice.

Aerobics Exercise and Health

With the development of the social economy and improvement of people's living standards in recent years, the ratio of cardiovascular disease (CVD) and obesity has increased significantly (Ogden & Carroll, 2010). Since CVD is the leading cause of mortality, morbidity and health care cost, this places an enormous burden on patients and their families. Thus, it is reasonable to encourage primary and secondary prevention of coronary artery disease (CAD) (Heidenreich et al., 2011). It is well known that regular physical activity, especially aerobic exercise, reduces cardiac risk factors, such as hyperlipidemia, stroke, type 2 diabetes mellitus (T2DM), and obesity (Reiner, Niermann, Jekauc, & Woll, 2013; ACSM, 2017). The American College of Sports Medicine (ACSM) has published specific exercise recommendations that performing aerobic exercise at least 5 days/week of moderate exercise or 3 days/week of vigorous intensity exercise could achieve and maintain cardiorespiratory fitness (ACSM, 2017). Many countries like America, Europe (Montalescot et al., 2013), China (刘遂心, 2012; Ding, 2015), and Taiwan (Lee et al., 2008; Lee et al., 2009) have reported that exercise-based cardiac rehabilitation is an effective treatment for secondary prevention of CAD.

Swain and Franklin (2006) stated that individuals get a greater reduction of CVD risk with vigorous aerobic exercise (> 6METs) compared to moderate aerobic and intense physical activity. Similarly, higher intensity aerobic exercise also lower blood pressure (BP) and glucose levels.

Long term aerobic training (≥ 12 weeks) results in reduced body mass index (BMI), lower resting heart rate (HR), lower submaximal exercise HR, and decreased systolic BP with increased lean body mass (Wong et al., 2008; Thorogood et al., 2011). In conjunction with diet control, it may be an effective therapy for losing weight (Thorogood et al., 2011). A regular aerobic exercise program also improves brain function, memory, selective attention, and is believed to optimize the executive functions in healthy people (Guiney and Machado, 2013).

Modes of aerobic exercise

The best way to improve cardiopulmonary function is to use large muscle groups while performing aerobic exercise (Garber et at., 2011). Different aerobic exercise modalities require different levels of skill and intensity to perform. ACSM (2017) categorizes four groups of exercise based on an individual's fitness condition. Group A is suitable for all adults and includes walking and cycling. Running, rowing, elliptical exercise, and stepping require more physical fitness reserve and thus are categorized in group B. Swimming, and cross-country skiing are skill dependent and are in group C. Recreational exercise like basketball and soccer are listed in group D.

Energy expenditure

The definition of energy expenditure (EE) is the amount of energy that one requires for basic physiological work and physical activity. The measurement of EE is accomplished with direct calorimetry and indirect calorimetry. Direct calorimetry requires evaluating the amount of heat produced during metabolism. Indirect calorimetry requires measuring the amount of energy produced though the oxidative process from respiratory gas exchange in the body (Frayn, 1983). Energy metabolism is the process that generates adenosine triphosphate (ATP) from nutrients. ATP is formed from the conversion of carbohydrate or fat. During aerobic exercise, the energy expended by fat is 4.7 kcal per liter of O_2, and carbohydrate is 5.05kJ per liter of O_2 (Kang, 2008).

Indirect calorimetry was used in most studies which compared EE among different exercise machines (Brown, Cook, Krueger, & Heelan, 2010; Moyna et al., 2001; Zeni, Hoffman, & Clifford, 1996). There are many reasons for differenes and EE: racial differences (Hunter, Weinsier, Darnell, Zuckerman, & Goran, 2000), body size (Drenowatz et al., 2014), and types of exercise (Drenowatz et al., 2014; Moyna et al., 2001; Zeni et al., 1996).

Energy Expenditure From Different Modes of Aerobic Exercise

Treadmill

Walking at a speed of 5.6 km/hr with no grade requires approximately 5 kcal/min in men and 3.9 kcal/min in women. Running at 12 km/h expends 14 kcal/min and 11 kcal/min in men and women, respectively (Wilmore and Costill, 2004). The treadmill is considered the gold standard for measuring VO_2peak because running on a sloped treadmill requires the largest muscle mass compared to other indoor exercise machines. The energy expenditure(VO2max[ml/kg/min]) of walking on treadmill can be calculate by 3.5+(0.1×speed[m/min]) +(1.8×speed×grade[%]), and the equation of running on a treadmill is followed by 3.5+(0.2×speed[m/min]) +(0.9×speed×grade[%])(ACSM, 2005). Several studies (Moyna et al., 2001; Zeni et al., 1996) have shown that exercise on a treadmill at each rating of perceived exertion

(RPE) 11, 13, 15 expends more calories compared to a cycling ergometer, rowing ergometer, stair stepper, and cross-country skiing simulator. Kravitz, Robergs, Heyward, Wagner, and Powers (1997) found the treadmill had the highest VO_2 and EE compared to cross-country skiing, cycle ergometer, and riding exercise. Similarly, the investigation by Rhomas, Ziogas, Smith, Zhang, and Londeree (1995) found that the VO_2 for treadmill exercise was higher than skiing, stepping, cycling and rowing. Another study indicated that exercise on a treadmill consumes more oxygen compared to cycling ergometer when performing at 85% of maximal HR (Hill, Oxford, Duncan, & Price, 2015) with maximal effort maximal exercise test (Carlen, Astrom, Nylander, & Gustafsson, 2017).

<u>Elliptical</u>

Lu, Chien, and Chen (2007) found that elliptical training can reduce the loading rate in the lower limbs compared to walking. Thus, this machine is more suitable for individuals who are overweight or obese or have back pain or leg injury (Porcari, Zedaker, Naser, & Miller, 1998). Based on research by Damiano, Norman, Stanley, and Park (2011), elliptical training showed better transfer to over ground walking than cycling. Moreover, it required larger loading on quadriceps and hamstring than walking, thus, it is more effective for muscle strengthening.

Mier and Feito (2006) measured stride rate, resistance and calculated EE on an elliptical trainer. They found that the metabolic cost is approximately 0.1 ml/kg/stride. Increasing stride rate and resistance also increases VO_2, VE, HR, and RPE. The EE of exercise on the elliptical machine is similar to running on the horizontal treadmill at the same stride rate. They also found that an individual has higher VO_2, V_E, and total EE when using both arm-leg during exercise compared to leg only exercise.

Dalleck, Kravitz, and Robergs (2004) evaluated 20 young participants VO_2 and

HR on the elliptical cross-trainer and treadmill. Their results revealed that working at maximal intensity on the treadmill and the elliptical cross-trainer had similar maximal physiological values. Egana and Donne (2004) estimated the VO_2max and V_Emax before and after 12 weeks of training on the treadmill, elliptical, and stair-climbing machine. They observed similar physiological improvement, both in terms of VO_2max and $V_{E,}$ for all three modalities when training intensity, frequency, and volume were similar. There was no significant difference between three machines on improving fitness. Also, this study supports the concept that both stair-climbing and elliptical training provide sufficient intensity to improve cardiopulmonary fitness.

Similar results were seen in a study by Brown et al. (2010). They investigated VO_2, EE, and HR on the treadmill and elliptical trainer at RPE 13 on the 6-20 Borg scale. The results showed that VO_2 and EE were not different between the treadmill and elliptical trainer.

Elliptical and treadmill showed similar EE during submaximal and maximal exercise testing (Dalleck et al., 2004; Egana &Donne, 2004; Mays, Boér, Mealey, Kim, & Goss, 2010; Brown et al., 2010). The result indicated that both aerobic exercises provide similar cardiopulmonary fitness and caloric expenditure benefits. Thus, the selection of which machine would depend on an individual's preference and fitness goal.

<u>Stair Climber and Rowing Ergometer</u>

Stair climbing has been shown to improve musculoskeletal and cardiovascular fitness (Boreham, Wallace, & Nevill, 2000; Teh, & Aziz, 2002). According to ACSM (2005), the equation to estimate EE of stepping is $3.5 + (0.2 \times \text{steps/min}) + (1.33 \times 1.8 \times \text{step height[m]} \times \text{step/min})$. Teh and Aziz (2002) measured the EE from field-based stair climbing. The height for each stair was 15cm. The average EE for climbing 180 steps or 11 stories with a constant pace was 10.2 kcal/min.

With the popularity of outdoor water activities, rowing has become a popular exercise. To maximize the EE from rowing machine, they are usually designed with a sliding seat. Rowing requires working the large leg muscles, the shoulders, and the back. The EE is varied based on the level of familiarity with a rowing machine (Hagerman, Lawrence, & Mansfield, 1988). The rowing machine is contraindicated with spinal injuries (Hagerman et al., 1988; Ingham et al., 2002). Thus, patients with spinal cord or low back pain should avoid performing this exercise.

Moyna et al. (2001) compared EE among six indoor machines at RPE 11, 13, 15. The treadmill was the most energy demanding exercise while cycling burned the fewest calories. The EE was followed by cross-country skiing, stair stepping, rowing, and rider. On the other hand, the treadmill expended similar calories as rowing and stair climbing in the female group. The study by Zeni et al. (1996) showed a similar trend as the EE for treadmill was the highest, followed by stair climbing, rower, and cycling. Similarly, Thomas et al. (1995) found that EE for treadmill was higher than skiing, followed by stepping, rowing, and cycling.

Hagerman et al. (1988) compared the cardiopulmonary responses at similar intensities on rowing and cycling ergometers. Participants were 20 to 70 years old volunteers. This wide range of the population is more likely to show up in the public health facility or gymnasium. The results found both metabolic and cardiopulmonary responses (VE, VO_2, and HR) were significantly higher in rowing compared to cycling at maximal exercise. Another study by Bouckaert, Pannier, and Vrijens (1983) found that VO_2 was higher during rowing than cycle ergometry during submaximal exercise, both in untrained participants and among athleltes. During maximal exercise testing, VO_2peak was significantly lower in rowing than that of cycling in non-oarsmen, while oarsmen showed no difference between the two machines. Maximal exercise in untrained females and trained rowers illustrated different responses during maximal exercise test on rowing and cycling ergometers (Mahler, Andrea, & Ward, 1987). Rowing athletes in this study obtained lower VO_2peak on rowing than cycling, while the untrained group showed no difference. VO_2 at ventilatory threshold (VT) was higher during rowing in the rower group.

Arm Crank Ergometer

An arm crank ergometer is a good machine for elderly adults with impaired balance or lower extremity weakness. Several studies (Donath et al., 2013; Stemplewski, Maciaszek, Salamon, Tomczak, & Osiński, 2012) have found that elderly individuals have a higher center of pressure displacement after exercise due to fatigue, which may result in an increasing fall risk. Hill et al. (2015) observed no post fatigue effects nor unstable posture after working on an arm ergometer. Thus, an arm crank ergometer could be an alternative exercise modality for older individuals trying to maintain physical fitness without reducing balance control.

Cycling Ergometer

Cycle ergometry is a common indoor exercise machine. It is wildly used as an alternative to the treadmill. Individuals who are obese, have knee joint or hip joint problem (Johnston, 2007), and other physical limitations can reduce lower extremity loading by using this machine. Cycling ergometer is a gold standard for exercise testing in Europe (Myers et al., 2009). Energy expenditure on a cycling machine is equal to 3.5(resting) +3.5(horizontal) + (1.8×work rate [kg·m/min]/body mass [kg]) (ACSM, 2005).

Cycling requires less energy at RPE 11, 13, 15 than a treadmill, cross-country ski simulator, rowing, and stair climber (Moyna et al., 2001; Zeni et al., 1996). Hill et al. (2015) observed a postural sway in healthy older females on the treadmill, cycle ergometer, and arm crank ergometer. The intent of this study was to have participants exercise to 85% of HR_{max}. The results showed that VO_2 on the treadmill was greater than the cycle ergometer and greater than that of an arm ergometer. But HR showed no difference between the treadmill and the cycle ergometer, but was higher than on the arm ergometer. A similar result was seen by Mays et al. (2010). They compared VO_2peak on a treadmill, cycle, and elliptical at 85% of HR_{max}. The results found that the VO_{2peak} of the cycle ergometer is significantly less than that of the treadmill and elliptical.

Muscular Fitness Comparison

Bouillon, Baker, Gibson, Kearney, and Busemeyer (2016) measured the lower extremity muscle usage during exercise on a treadmill, elliptical, upright bike, and recumbent bike. They found working on an elliptical has similar muscle activity to the treadmill, but is greater than cycling. A study by Rogatzki et al. (2012) compared kinetics, muscle activation, and joint kinematics between elliptical and stepping exercise. They found that elliptical allowed greater ankle plantar flexion, knee extension, and hip flexion compared to stepping.

Further Research

Our study concluded that the treadmill and elliptical machine are the most energy demanding aerobic exercises, followed by stair climbing, rowing, and cycling in males group. In females, exercising on a treadmill expends similar energy as stair stepping and rowing, and are greater than that of cycling during submaximal exercise. A gap in research was found on EE of the airdyne and arm crank ergometer. The results were inconclusive in the rowing machine. Thus, future studies are warranted regarding EE using the airdyne, arm crank ergometer and the rowing machine.

Summary

Aerobic exercise is the most efficient way to improve cardiopulmonary benefits. Studies comparing aerobic machines show that the treadmill and elliptical trainer share similar EE and cardiopulmonary intensity. Cycling is a non-weight bearing exercise, as predicted, requires a lower EE compared to a treadmill and elliptical. Stair climbing and rowing require more EE than cycling during submaximal exercise, yet, the variety of results depend upon the experience of the user.

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