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Metabolic Cost of Stride Rate, Resistance, and Combined Use of Arms and Legs on the Elliptical Trainer

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We measured the effects of stride rate, resistance, and combined arm-leg use on energy expenditure during elliptical trainer exercise and assessed the accuracy of the manufacturer's energy expenditure calculations. Twenty-six men and women (M age = 29 years, SD = 8; M body weight = 73.0 kg, SD = 15.2) participated. Twenty-two participants performed two tests, one without the arm poles (leg-only) and the other with arm poles (combined arm-leg). The other 4 participants performed one test without the arm poles. Both tests consisted of six 5-min stages (two stride rates, 110 and 134 strides·min^{-1}, and three resistance settings: 2, 5, and 8). Steady-state oxygen uptake (VO_2), minute ventilation (VE), heart rate (HR) and rating of perceived exertion (RPE) were measured. Repeated measures analysis of variance determined higher ($p < .001$) VO_2, VE, and RPE, but not HR, during combined arm-leg versus leg-only exercise at any given intensity. Increases in stride rate and resistance increased VO_2, VE, RPE, and HR with the greatest effect on VE and HR from Levels 5 to 8. The manufacturer's calculated energy expenditure was overestimated during both tests. Although the oxygen cost for elliptical trainer exercise was calculated to be approximately 0.1 ml·kg^{-1} per stride and 0.7 ml·kg^{-1}·min^{-1} per resistance level, VO_2 varied widely among individuals, possibly due to differences in experience using the elliptical trainer, gender, and body composition. The elliptical trainer offers (a) a variety of intensities appropriate for most individuals and (b) both arm and leg exercise. Due to the wide variability in VO_2, predicting the metabolic cost during elliptical trainer exercise for an individual is not appropriate.

Key words: efficiency of movement, estimating energy expenditure, oxygen cost of exercise, predicting oxygen uptake

The elliptical trainer has gained widespread popularity among fitness enthusiasts. It is particularly appealing as a low-impact alternative to treadmill exercise and offers both leg and arm workouts. Peak oxygen uptake and heart rate have been shown to be similar between treadmill running and elliptical trainer exercise, indicating the elliptical trainer is comparable to the treadmill in training intensities (Mercer, Dufek, & Bates, 2001). At a given submaximal oxygen uptake or a self-selected pace, physiological responses, such as heart rate, blood pressure, and perceived exertion, are similar between treadmill running and elliptical trainer exercise (Crommett, Kravitz, Wongsathikun, & Kemerly, 1999; Egana & Donne, 2004; Pecchia, Evans, Edwards, & Bell, 1999; Porcari, Zedaka, Naser, & Miller, 1998). These studies indicate that elliptical trainer exercise, when compared to treadmill running, provides adequate stimuli for aerobic exercise adaptations and optimal training volume for health benefits, at least in healthy, nonobese, relatively young men and women.

Due to the elliptical trainer's popularity, fitness testing and exercise prescription specific to it are beneficial. Total exercise energy expenditure or training volume is strongly associated with the health benefits of exercise (Oja, 2001), and weight control is a significant motivation for many to exercise (Cash, Novy, & Grant, 1994); therefore, prescribing appropriate exercise intensity with these goals in mind is essential. To prescribe exercise intensity specific to an individual who exercises on an elliptical trainer, it is necessary to

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know the metabolic cost of stride rate and resistance and the addition of arm exercise, because certain physiological responses, such as heart rate and rating of perceived exertion, differ according to exercise mode (Batte, Darling, Evans, Lance, Olson, & Pincivero, 2003; Porcari et al., 1998). Further, relying on the manufacturer's calculations of energy expenditure may not be appropriate, as has been demonstrated with stair stepping machines (Howley, Colacino, & Swensen, 1992). Therefore, the purpose of this study was to (a) measure the effects of stride rate, resistance, and combined arm-leg use on energy expenditure and other physiological responses during elliptical trainer exercise and (b) assess the accuracy of the manufacturer's calculations.

Method

Participants

The Barry University Institutional Review Board for human research participation approved this study, and all participants read and signed an approved informed consent form prior to the study. Participants were recruited from the Barry University fitness center. Recruitment flyers were placed near the elliptical trainers to target users of the machines. Participants were included only if they had two or fewer risk factors, had no signs or symptoms of cardiopulmonary or metabolic disease, were regular users of the fitness center, and regularly performed some form of aerobic activity (American College of Sports Medicine [ACSM], 2006). Twenty-six participants (12 men and 14 women), ranging in age from 22 to 51 years and ranging in body weight from 48.6 to 110.5 kg (*M* age = 29 years, *SD* = 8; *M* body weight = 73.0 kg, *SD* = 15.2), performed exercise tests on an elliptical trainer (EFX®534i; Precor, Inc., Woodinville, WA).

Protocol

Twenty-two participants performed two tests, one without the arm poles (leg-only) and the other with arm poles (combined arm-leg), on separate days within 1 week. Due to dropout, the other 4 participants performed only one test without the arm poles. Both tests consisted of six 5-min stages during which oxygen uptake (VO_2) and heart rate (HR) were measured continuously. Participants performed three stages at a stride rate of 110 strides·min^{-1} and three at 134 strides·min^{-1}. Stride rate displayed on the machine was validated with a metronome. Moving one leg from the back to forward position was considered one stride. Stages were performed at the manufacturer's resistance settings—2, 5, and 8—at 110 strides·min^{-1} and again at 134 strides·min^{-1}. These settings were chosen because they were frequently used by individuals in the fitness center and provided a wide enough range to determine effects.

Most of the participants were already acquainted with the elliptical trainer: 23 used it regularly, 1 had begun using it 1 week (three sessions) prior to the study, and 2 had never used it. To become acquainted with the exercise, these 2 participants exercised on the elliptical trainer three times, at least 15–30 min each, prior to participating in the study.

Measurements

VO_2 was measured continuously during each stage, using open circuit spirometry (TrueOne® 2400; ParVo Medics Inc., Salt Lake City, UT). Expired gases were collected and analyzed for volume and fractional oxygen and carbon dioxide. The metabolic system was calibrated prior to each test. Steady-state VO_2 and minute ventilation (VE) were recorded in 20-s averages during the last 2 min of each stage. HR was measured using telemetry (Polar™, Lake Success, NY), and rating of perceived exertion (RPE) was determined using Borg's scale (Borg, 1982) during steady-state measures.

Before each stage, the elliptical trainer was programmed with the individual's body weight and age and set on the manual course program, which allowed resistance to be adjusted as needed. The total number of strides completed during a 5-min period was recorded to determine average stride rate. Stride rate was constantly displayed during the test so the participant could try to maintain 110 or 134 strides·min^{-1}. The manufacturer's display of total kilocalories at the end of each 5-min period was recorded, and rate of energy expenditure (kcal·min^{-1}) was calculated from this number. Rate of energy expenditure was also calculated from measured VO_2 using the standard conversion of 5 kcal per liter of oxygen (ACSM, 2006). From these calculations, the difference between actual and manufacturer's calculations for energy expenditure was determined.

Statistical Analyses

Repeated measures analysis of variance (ANOVA) was used to analyze the data to determine the effects of stride rate, resistance, and the combined use of arms and legs (mode) on VO_2, VE, HR, and RPE (n = 22). The percentage of difference between manufacturer's and measured kcal·min^{-1} was also analyzed. Bonferroni post hoc tests were performed to distinguish effects of the three resistance levels. Multiple linear regression analysis was used to predict VO_2 using stride rate and resistance as independent variables. Variance (R^2), standard error of estimate (*SEE*), and a regression formula were calculated and reported for both leg-only (n = 26) and combined arm-leg exercises ($n = 22$). For the regression analyses, VO_2 was estimated to be 3.5 ml·kg^{-1}·min^{-1} at 0 strides·min^{-1} and a resistance level of 0 for all participants. Significance was set at $p \leq .05$, and data were expressed as means and standard deviations.

Results

Twenty-two participants completed both leg-only and combined arm-leg exercise tests, and 4 completed just the leg-only tests. Each participant completed the six stages during each test. The average stride rates for the tests were 112 (± 1) and 133 (± 2) strides·min^{-1} for both the leg-only and the combined arm-leg tests.

Oxygen Uptake

ANOVA revealed an effect of mode on VO_2, $F(1, 126) = 18.0$, $p < .001$, such that VO_2 was higher during combined arm-leg exercise (see Table 1). There was an interactive effect between mode and stride rate, $F(1, 126) = 4.8$, $p < .03$, with an increase in VO_2 from 110 to 134 strides·min^{-1} during combined arm-leg exercise compared to leg-only (17% vs. 14%). Effects of stride rate, $F(1, 126) = 72.4$, $p < .001$, and resistance, $F(1, 126) = 59.7$, $p < .001$, on VO_2 were significant (see Tables 2 and 3). Post hoc tests revealed that VO_2 increased with each resistance increase for leg-only and combined arm-leg exercise ($p < .003$). From Levels 2 to 8, VO_2 increased about 25% for both leg-only and combined arm-leg exercises.

Table 1. Comparison of the overall physiological responses between leg-only and combined arm-leg elliptical trainer exercises

	Leg-only		Combined arm-leg	
	M	*SD*	*M*	*SD*
VO_2 (ml·kg^{-1}·min^{-1})	18.7	3.0	19.2*	3.0
VE (l·min^{-1})	35.9	7.8	37.7*	8.3
HR (b·min^{-1})	125	20	125	23
RPE	10.9	1.9	10.3*	1.9

Note. *M* = mean; *SD* = standard deviation; VO_2 = oxygen uptake; VE = minute ventilation; HR = heart rate; RPE = rating of perceived exertion.
*$p < .05$ from leg only.

Ventilation

ANOVA revealed an effect of mode on VE, $F(1, 126) = 43.1$, $p < .001$, such that VE was higher during combined arm-leg exercise (see Table 1). There was no interactive effect with stride rate or resistance. Effects of stride rate, $F(1, 126) = 28.7$, $p < .001$, and resistance, $F(1, 126) = 19.1$, $p < .001$, on VE were significant (see Tables 2 and 3). Post hoc tests revealed that VE did not increase from Levels 2 to 5 but did increase from Levels 5 to 8 ($p < .001$).

Heart Rate

HR did not differ between leg-only and combined arm-leg exercises (see Table 1). Both stride rate, $F(1, 126) = 12.5$, $p < .002$, and resistance, $F(1, 126) = 8.8$, $p < .001$, had significant effects on HR (see Tables 2 and 3). Post hoc tests revealed that HR did not increase from Levels 2 to 5 but did increase from Levels 5 to 8 ($p < .001$).

Rating of Perceived Exertion

ANOVA revealed an effect of mode on RPE, $F(1, 126) = 51.8$, $p < .001$, such that RPE was lower during combined arm-leg exercise (see Table 1). There was

Table 2. Physiological responses during leg-only elliptical trainer exercise

Stride rate	110						134					
Resistance	2		5		8		2		5		8	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VO_2 (ml·kg^{-1}·min^{-1})	15.9*/**	2.2	17.2**	2.1	19.3	2.1	17.9*/**	2.4	19.3**	1.9	22.8	2.1
VE (l·min^{-1})	30.2**	5.9	32.8**	6.1	36.4	5.7	34.4**	7.4	37.2**	6.8	44.6	7.1
HR (b·min^{-1})	113**	14	119**	16	127	19	122**	18	128**	20	141	22
RPE	9.2*/**	1.7	10.0**	1.4	11.0	1.5	11.2*/**	1.5	11.7**	1.8	12.6	1.7

Note. *M* = mean; *SD* = standard deviation; VO_2 = oxygen uptake; VE = minute ventilation; HR = heart rate; RPE = rating of perceived exertion.
*$p < .05$ from Level 5.
**$p < .05$ from Level 8.

no interactive effect with stride rate or resistance. Effects of stride rate, $F(1, 126) = 42.5$, $p < .001$, and resistance, $F(1, 126) = 67.9$, $p < .001$, on RPE were significant (see Tables 2 and 3). Post hoc tests revealed that RPE increased with each increase in resistance level for both leg-only and combined arm-leg exercise ($p < .04$).

Manufacturer's Calculations of Energy Expenditure

Table 4 presents the percentage of differences between the measured rate of energy expenditure and the manufacturer's calculations, which overestimated energy expenditure for both leg-only and combined arm-leg exercise. ANOVA determined that mode had a significant effect, $F(1, 126) = 16.3$, $p < .001$, such that the overestimation was less for combined arm-leg exercise. Resistance, $F(1, 126) = 7.9$, $p < .002$, but not stride rate had a significant effect on differences. A post hoc test revealed the manufacturer's overestimation was less at Level 2 compared to Levels 5 or 8 ($p < .004$).

Prediction of Oxygen Uptake

Two separate multiple linear regression analyses were performed using data from the leg-only and combined arm-leg exercise tests; adjusted $R^2 = .90$, $SEE = 1.90$ ml·kg^{-1}·min^{-1} ($p < .001$) for the leg-only test. The regression equation for leg-only elliptical-trainer exercise was:

$$VO_2\ (\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 3.48 + (0.097)\text{stride rate} + (0.678)\text{resistance}$$

For the combined arm-leg exercise test, measures were $R^2 = .95$ and $SEE = 1.75$ ml·kg^{-1}·min^{-1} ($p < .001$). The regression equation for combined arm-leg elliptical-trainer exercise was:

$$VO_2\ (\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 3.34 + (0.101)\text{stride rate} + (0.713)\text{resistance}$$

Gender Effects

ANOVA revealed no interactive effect between gender and exercise mode; therefore, responses for leg-only and combined arm-leg exercises were averaged and the following analyses were completed using the average data. Overall, women had lower VO_2, $F(1, 120) = 11.4$, $p < .001$, lower VE, $F(1, 120) = 14.0$, $p < .001$, higher HR, $F(1, 120) = 6.1$, $p < .02$, and higher RPE, $F(1, 120) = 6.2$, $p < .02$, compared to men. There were no interactive effects between gender and stride rate; however, there was an interactive effect between gender and resistance for VO_2, $F(1, 120) = 3.7$, $p < .03$, such that the increase in VO_2 from Levels 2 to 8 was greater in women (see Table 5). Post hoc tests revealed that VO_2 increased in women with each increase in resistance level, but the increase in men was evident only from Levels 5 to 8. VE, HR, and RPE increased only from Levels 5 to 8 in women, where no differences between Levels 2 and 5 were noted. In men, VE differed only from Levels 2 to 8, and HR and RPE did not differ from one resistance level to another.

Discussion

Our data describe the effects of stride rate, resistance, and the combined use of arms and legs on VO_2 and other steady state physiological responses during elliptical trainer exercise. As expected, increases in stride rate and resistance resulted in higher VO_2, VE, HR, and RPE, regardless of whether participants used their arms in the workout. The elliptical trainer offers a wide range of resistance levels (1 to 20), and stride rate can vary from a slow walking to a fast running pace according to individual preference. Although we increased resistance only to Level 8 and stride rate to 134 strides·min^{-1}, we observed a relatively wide range of responses. From 110

Table 3. Physiological responses during combined arm-leg elliptical trainer exercise

Stride rate	110						134					
Resistance	2		5		8		2		5		8	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VO_2 (ml·kg^{-1}·min^{-1})	16.1*/**	1.5	17.2**	1.6	19.8	1.9	18.5*/**	1.8	20.1**	1.9	23.6	2.2
VE (l·min^{-1})	31.6**	6.4	33.6**	6.1	38.3	6.2	36.6**	7.2	39.5**	7.5	47.0	7.6
HR (b·min^{-1})	112**	16	117**	18	126	19	123**	22	129**	23	142	26
RPE	8.5*/**	1.4	9.4**	1.5	10.5	1.5	10.3*/**	1.5	11.2**	1.7	12.0	1.8

Note. *M* = mean; *SD* = standard deviation; VO_2 = oxygen uptake; VE = minute ventilation; HR = heart rate; RPE = rating of perceived exertion.
*$p < .05$ from resistance 5.
**$p < .05$ from resistance 8.

strides·min^{-1} at Level 2 to 134 strides·min^{-1} at Level 8, VO_2 increased 6.9 and 7.5 ml·kg^{-1}·min^{-1} during leg-only and combined arm-leg exercise, respectively. Accordingly, HR increased 28 and 30 beats·min^{-1}, and RPE increased from 9.2 to 12.6 and 8.5 to 12.0 for leg-only and combined arm-leg exercise, respectively. These responses indicate the elliptical trainer provides a wide range of intensities suitable for most individuals. This is important, as some may find the elliptical trainer to be more appealing than the treadmill, particularly overweight individuals or those with back or leg injuries, because of its lower impact forces (Porcari et al., 1998).

We found the metabolic cost on the elliptical machine to be approximately 0.1 ml·kg^{-1} per stride for both leg-only and combined arm-leg exercises. Because the distance traveled per stride was 0.495 m on this particular elliptical trainer, the metabolic cost of stride rate was similar to that of the horizontal component of running, which is 0.2 ml·kg^{-1} per meter (Margaria, Cerretelli, Aghemo, & Sassi, 1963). We also found that increasing resistance from one level to the next increased VO_2 approximately 0.7 ml·kg^{-1}·min^{-1} for both leg-only and combined arm-leg exercises. Although this is similar to the metabolic cost of increasing treadmill incline by 1% (Margaria et al., 1963), resistance on this particular elliptical trainer cannot be equated to the vertical component of running (i.e., Level 1 is not the same as 1% grade on a treadmill). Resistance level on this elliptical trainer was increased by adding resistance to the flywheel, similar to a cycle ergometer. Therefore, unlike the metabolic cost of running up a grade, adding resistance does not depend on stride rate and should not be equated to the vertical component of running or walking.

VO_2 and VE were higher and RPE was lower during the combined arm-leg exercise compared to leg-only. These results are similar to previous studies that showed higher VO_2 and lower RPE when arm exercise was added to leg-cycle exercise (Gutin, Ang, & Torrey, 1988; Hoffman, Kassay, Zeni, & Clifford, 1996); however, others have observed no differences in physiological responses between these exercise modes at a given power output (Eston & Brodie, 1986). The lower RPE experienced by our participants during combined arm-leg exercise indicates that they experienced a lower relative intensity when arms were included. It is possible that VO_2max during combined arm-leg exercise is greater than leg-only exercise on the elliptical trainer. Supporting this, combining arm and leg cycle exercise such that 10% of the power output is distributed to the arms has elicited a greater VO_2max response (Nagle, Richie, & Giese, 1984). Consequently, one could achieve a greater total energy expenditure using both arms and legs compared to leg-only exercise. Further, one could delay leg or arm fatigue by alternating arm-leg exercise with leg-only exercise during a workout, thus, making it easier to sustain an energy expenditure rate for a longer period.

Table 4. The percents of overestimation by the manufacturer's calculations on rate of energy expenditure

Stride rate	R	Leg only			Combined arm-leg		
		M	*SD*	Range	*M*	*SD*	Range
110	2	21.3*	11.7	-4.9–46.5	20.8*	9.4	5.3–34.9
	5	28.5	9.9	9.0–41.7	28.1	9.0	9.4–39.8
	8	30.4	6.6	11.4–42.8	28.3	6.1	15.6–35.9
134	2	23.0*	12.5	-6.7–49.8	20.7*	10.2	-4.9–36.0
	5	29.1	8.8	7.0–47.1	26.2	8.6	6.0–38.7
	8	27.1	6.4	10.5–39.2	24.6	5.9	8.9–33.7

Note. M = mean; *SD* = standard deviation; R = resistance.
**p* < .05 from Levels 5 and 8; a negative value indicates manufacturer underestimation.

Table 5. Effects of resistance on physiological responses during elliptical trainer exercise in men and women (stride rate and mode data were combined)

Stride rate	Men						Women4					
Resistance	2		5		8		2		5		8	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VO_2 (ml·kg^{-1}·min^{-1})*	18.2**	2.3	19.1**	2.4	21.3	2.9	16.2*/**	1.5	17.9**	1.8	21.4	2.6
VE (l·min^{-1})	36.4**	6.2	38.2	6.7	42.7	7.6	30.6**	6.3	33.7**	6.6	40.7	7.8
HR (b·min^{-1})	115	19	119	20	127	21	119**	17	127**	19	140	21
RPE	9.6	1.8	10.3	2.0	11.0	2.0	9.9**	1.6	10.9†	1.5	12.0	1.3

Note. M = mean; *SD* = standard deviation; VO_2 = oxygen uptake; VE = minute ventilation; HR = heart rate; RPE = rating of perceived exertion
**p* < .05 from Level 5.
***p* < .05 from Level 8.

We found the manufacturer's calculations greatly overestimated energy expenditure, especially at the higher resistance settings. The manufacturer's calculations did not factor in arm use; therefore, when arms were included in the workout, the overestimation was less due to the higher energy expenditure from the combined arm-leg exercise. We found a relatively wide range of VO_2 responses at any given intensity on the elliptical trainer. For instance, at 110 strides·min^{-1} and Level 5, individual VO_2 ranged from 13.6 to 22.2 ml·kg^{-1}·min^{-1} during leg-only exercise. Because of this wide range of individual responses, the manufacturer's inaccuracy varied widely among participants, and, in fact, the manufacturer's calculation underestimated energy expenditure for 1 participant.

Several factors might contribute to the varied VO_2 responses. A possible contributing factor, at least during the combined arm-leg exercise, was the ratio of arm work to total work and the relative fitness of the arms to legs (Bergh, Kanstrup, & Ekblom, 1976). Differences in body mass and body composition may also contribute to differences in efficiency of movement. Previously, walking efficiency was shown to be negatively correlated with body fatness in both men and women (Chen, Acra, Donahue, Sun, & Buchowski, 2004). Weight loss may also contribute to improved efficiency, at least in postobese men and women (Geissler, Miller, & Shaw, 1997). In addition to these effects, changes in exercise intensity are associated with within-participant variation in efficiency (Chen, et al., 2004; Gaesser & Brooks, 1975).

The fact that both men and women participated in this study could also have contributed to the variability in VO_2 (Donnelly & Smith, 2005); however, gender differences in VO_2 were observed only during the lowest intensity (Level 2). Nevertheless, the improved movement efficiency in women may be related to experience. All female participants reported prior experience on the elliptical trainer, and several included it more frequently during their visits to the fitness center compared to only 8 of the 10 male participants with prior experience.

In our attempt to include participants who represented frequent clientele at a fitness center, we may have limited our study by including both men and women and not controlling for body composition. As a result, physiological responses to elliptical trainer exercise varied, although almost all participants used the elliptical trainer regularly. This did not detract, however, from the study purpose, to measure the effects of stride rate and resistance and the combined use of arms and legs. Except for the effects of resistance on VO_2, gender did not confound the physiological responses to changes in stride rate or combined arm-leg use. We found the increases in resistance and stride rates similar to the effects of treadmill running. However, because of the variability in participants' physiological responses, an accurate prediction formula is difficult to establish.

In summary, the elliptical trainer offers a variety of intensities appropriate for most individuals, comparable to treadmill exercise. At a given stride rate and resistance, combining arm with leg exercise increases energy expenditure somewhat, while maintaining a similar heart rate and eliciting a slightly lower RPE. It remains to be shown, however, how the combined arm-leg exercise compares to leg-only, with respect to training responses and self-selected intensities and durations. We also demonstrated that the manufacturer overestimated energy expenditure; however, the degree of error varied greatly among individuals as a result of varying VO_2 responses. Further research is necessary to elucidate the effects of experience and body composition on VO_2 responses during elliptical trainer exercise.

For practical purposes, we do not recommend that exercise physiologists use metabolic equations to predict an individual's energy expenditure when prescribing elliptical trainer exercise; however, our data can be used as a guide to prescribe changes in exercise intensity. Further, we do not recommend relying on the manufacturer's estimates of energy expenditure to prescribe an appropriate exercise volume to an individual.

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