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Arm Use and Posture Alter Metabolic Cost During Non-Impact Cardiovascular Cross Training at a Constant Machine Workload

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ABSTRACT

Sullivan EM, Hofmann CL, Fox MK, Juris PM. Arm Use and Posture Alter Metabolic Cost During Non-Impact Cardiovascular Cross Training at a Constant Machine Workload. **JEPonline** 2013;16(5):107-115. While the popularity of non-impact cardiovascular cross trainers has led to an increase in the number of metabolic studies that use the equipment, there is a lack of scientific information regarding the effect of incorporating arm use and postural shifts on metabolic cost. The aim of this study was to determine the influence of using the arms and shifting the posture on metabolic cost during exercise on a non-elliptical cross trainer. Fifteen healthy subjects exercised at ~70% of their age-predicted heart rate maximum while heart rate (HR), oxygen consumption (VO_2), and energy expenditure were measured. At a constant machine workload, the subjects exercised: (a) upright while unsupported; (b) upright while using the machine's handles; and (c) while leaning forward with the upper body anchored. Relative to working upright and unsupported, introducing arm use or a forward postural shift resulted in a significant increase in HR [73.4 ± 4.81% vs. 76.4 ± 4.51% (P=0.01) and 76.9 ± 5.92% (P<0.01)], VO_2 [23.37 ± 3.53 $mL \cdot min^{-1} \cdot kg^{-1}$ vs. 24.69 ± 3.67 (P=0.001) and 25.11 ± 3.74 (P<0.001)], and derived energy expenditure [9.126 ± 2.09 $kcal \cdot min^{-1}$ vs. 9.674 ± 2.16 (P<0.001) and 9.826 ± 2.07 (P<0.001)]. These results suggest that changes in user-machine interaction at a constant workload can have a significant, albeit small to moderate effect (d=0.258 - 0.649) on metabolic cost on this particular cross trainer.

Key Words: Exercise, Oxygen Consumption, Energy Expenditure

INTRODUCTION

Exercise equipment manufacturers have created multiple devices to develop cardiovascular fitness while minimizing the impact associated with jogging and running. The increasing popularity of non-impact cardiovascular cross trainers (CTs) has resulted in a large number of metabolic studies using this equipment. For example, it has been demonstrated that elliptical training and treadmill running result in a similar heart rate (HR) and metabolic cost at the same rating of perceived exertion (RPE) during steady state exercise (2,10). It has also been shown that the maximal rate of oxygen consumption (VO_2 max) can be directly measured or predicted with high reliability during exercise on elliptical trainers (6,7) and other CTs (15).

Most CTs provide a prediction of caloric expenditure in an attempt to quantify the conversion of energy required of an individual to match the machine's work output during exercise. There are obvious difficulties in such a prediction, especially since several factors can alter energy expenditure (EE) during cardiovascular exercise. Although age (11), gender (3), and body composition (4) are well studied, the change in EE as a result of altering one's 'user-machine interaction' during an exercise is less clear. Many CTs, for example, feature moving handles or stationary anchor points on which to grasp. In addition to the presence of these handles, the relative locations of these handles with respect to the exerciser might result in changes to the posture of the user. All of these permutations can potentially alter metabolic cost that is independent of changes to the machine's workload.

Few studies have investigated changes in EE for different user-machine interactions on elliptical trainers. In one such study, VO_2 was measured in healthy subjects during elliptical exercise with and without the use of the moving handles (12). The introduction of arm use resulted in a statistically significant increase in VO_2 of 2.6%, a 5.5% decrease in rating of perceived exertion (RPE), and no difference in HR relative to the 'legs only' exercise condition. These data suggest that changes in posture and/or stability can contribute to changes in VO_2. Other potential user-machine interactions, including stabilizing the upper body by using stationary anchor points, have not been adequately investigated. While the research by Mier and Feito (13) focused on differences in muscle activation and trunk kinematics as a result of grasping stationary handles, their study did not examine the metabolic costs of the required posture. Another important consideration is these studies focused on the elliptical trainer. Little related research has been reported on other forms of CTs. Given the differences in machine mechanics and available postures afforded by a variety of CTs, different devices may require different metabolic responses.

The purpose of this study was to quantify the changes in metabolic demand as a result of performing three different user-machine interactions on a CT at a constant machine work output. It was hypothesized that relative to an upright posture with no arm use, introducing arm workload would result in a decrease in efficiency (i.e., an increase in EE) and that anchoring the upper body would allow for a more efficient transfer of force to the footplates and thus a decrease in EE.

METHODS

Subjects

Fifteen healthy subjects (10 males, 5 females; age = 38 ± 12 yrs, weight = 80.0 ± 14.7 kg, height = 177.3 ± 10.7 cm) provided written informed consent prior to participation in the study. All subjects were confirmed to be of low risk for cardiovascular disease with a brief survey that was adapted from ACSM's cardiovascular risk stratification criteria. All experimental procedures were approved by the Institutional Review Board of the University of Massachusetts-Lowell.

Experimental Design
The device used in the present study was the Cybex Arc Trainer (Cybex International Inc., Medway, MA). This CT differs from a traditional elliptical trainer in two ways that warrant further discussion. First, the footplates travel along a fixed-length arcuate path as opposed to an elliptical pattern. Changing the incline of the machine alters the vertical displacement of the footplate along this fixed-length path. Therefore, when the incline is increased during exercise, it increases the range of motion at the hip and knee joints. In order to normalize the total joint work among subjects of different leg lengths, an appropriate incline was selected at which each subject reached a maximum of 70° of hip flexion, which was verified by a goniometer. Generally speaking, this led to taller subjects working at higher inclines than their shorter counterparts. Second, the moving handles travel in the same direction as the foot plates. This is different than most CTs that exhibit reciprocal arm-leg movement. In addition to the moving handles, the user has the option of leaning forward and anchoring the body by grasping stationary hand grips.

This study used a repeated measures cross-over design. The subjects were asked to exercise in 3 different conditions on a CT at a prescribed machine workload on two different testing days. To address the experimental hypothesis, the following 3 experimental conditions were examined (Figure 1): (a) Upright while unsupported (UR) – standing upright without grasping hand grips for support or using the moving handles; (b) Arms (ARM) – pulling on the mobile handles during upright exercise; and (c) Forward drive (FWD) – leaning forward while assuming an inclined posture and anchoring the body against the machine's console.

Figure 1. The Three User-Machine Interactions Tested: UR – Left, ARM – Center, FWD – Right. For each subject, all were performed at the same machine workload (i.e., incline, resistance, and speed).

Procedures
All subjects were familiarized with the CT, which included ~5 minutes of warm up at a low effort. Following the warm up, the subjects were instructed to begin exercising in the UR experimental condition and to reach a speed of 120 steps·min^{-1}. Resistance was increased until the subject's HR

reached between 65% and 75% of age predicted maximum (%APmax). The machine's work output (defined as the combination of speed, resistance, and incline) was unique for each subject, but held constant across the experimental conditions. Once the workload was determined, the subjects were fitted with a nose clip and a one-way breathing mouthpiece coupled to the TrueOne 2400 Metabolic Measurement System (ParvoMedics, Sandy, UT) for respiratory gas analysis. Heart rate was quantified with a Polar WearLink+ Coded Transmitter 31 strap (Polar, Kempele, Finaland) placed around the chest at approximately mid-sternum. The subjects were then instructed to begin exercise at the previously determined machine workload settings for the first of 3 experimental conditions. The total length of time between the determination of the machine workload and the start of the experimental trial was approximately 5 min during which HR was not tracked.

The subjects were allowed 2 min to acclimate to the experimental condition, at which time HR was noted. After an additional minute, HR was again noted and compared to the previous recording. If the HRs from successive recordings were within 5 beat·min^{-1}, then one final minute of exercise was performed at that condition. If the difference was greater than 5 beat·min^{-1}, this process was repeated for each passing minute until consecutive measures were within 5 beat·min^{-1}. Upon confirmation of steady state, 2 min of continuous breaths were collected before instructing the subject to switch to a different experimental condition. Most subjects were confirmed to have reached steady state during the first recording following the 2-min acclimation period. Therefore, most subjects spent 4 min in each experimental condition for a total of 12 min of exercise over the duration of the experiment. The above process was completed for all three experimental conditions. The experimental trial was performed on 2 different days, each within 7 days of each other at approximately the same time of day. The only difference between testing days was the order in which the subjects completed the experimental conditions, which was counterbalanced among all subjects and testing days.

Statistical Analyses

Averages for HR, VO_2 (mL·min^{-1}·kg^{-1}), and EE (kcal·min^{-1}) were computed over the final 2 min for each condition. EE was calculated by the default TrueOne Metabolic Measurement System software (OUSW 4.34, ParvoMedics, Sandy, UT). Intraclass correlation coefficients (ICC) were calculated as a measure of the reliability of the dependent variables across the two testing days. Additionally, a two-way ANOVA with experimental condition and subject as factors was run for each dependent variable to determine if testing day had a significant effect or interaction, as each testing session was performed in a different order for each subject. Following this confirmation, dependent variables for testing session one and two were averaged, and a one-way ANOVA with repeated measures was performed to determine the effects of experimental condition on outcome variables. Significance was set at 0.05 for all comparisons, with Bonferroni corrections applied *post hoc* when appropriate. Effect sizes (d) were calculated for all statistically significant comparisons (5). All statistical analyses were performed with SYSTAT (Version 12, SYSTAT Software Inc., Chicago, IL).

RESULTS

Two-way ANOVA tests confirm that there were no differences between testing days and no interaction between testing day and subject for HR (P=0.154, P=0.056), $\dot{V}O_2$ (P=0.400, P=0.720), or EE (P=0.683, P=0.824). In addition, the ICC for HR (0.702), $\dot{V}O_2$ (0.977), and EE (0.989) all demonstrate high reliability between testing days. Therefore, the dependent variables for session one and two were averaged and subsequent analyses were performed on the averages (Table 1, Table 2).

Table 1. Average Heart Rate, Oxygen Uptake, and Energy Expenditure for the Three Experimental Conditions.

	Upright Condition (UR)	Mobile Arms Condition (ARM)	Forward Drive Condition (FWD)
HR (beats·min^{-1})	132.3 ± 12.6	137.8 ± 13.1*	138.7 ± 15.2*
HR (%APmax)	73.4 ± 4.81	76.4 ± 4.51*	76.9 ± 5.92*
VO_2 (mL·min^{-1}·kg^{-1})	23.37 ± 3.53	24.69 ± 3.67*	25.11 ± 3.74**
EE (kcal·min^{-1})	9.126 ± 2.09	9.674 ± 2.16**	9.826 ± 2.07**

HR - heart rate, APmax - age predicted maximum, VO_2 - rate of oxygen consumption, EE - energy expenditure, UR - upright condition, ARM - mobile arms condition, FWD - forward drive condition; *P<0.01 relative to UR; **P<0.001 relative to UR

Table 2. Cohen's Effect Sizes (d) for Upright Unsupported (UR) Relative to Using the Arms (ARM) and Leaning Forward Conditions (FWD) for the Three Dependent Variables Under Investigation.

	UR vs. ARM	UR vs. FWD
HR	0.643	0.649
VO_2	0.367	0.478
EE	0.258	0.336

HR - heart rate, $\dot{V}O_2$ - rate of oxygen consumption, EE - energy expenditure, UR - upright condition, ARM - mobile arms condition, FWD - forward drive condition

Heart Rate

Mean HR responses for the 3 experimental conditions were 132.3 ± 12.6, 137.8 ± 13.1, and 138.7 ± 15.2 beats·min^{-1} for UR, ARM, and FWD, respectively. When expressed as a percentage of age predicted maximum, HR (%APmax) increased from 73.4 ± 4.81% during UR to 76.4 ± 4.51% for ARM and 76.9 ± 5.92% for FWD. The increases were statistically significant for ARM (P=0.010) and FWD (P=0.002) relative to UR, with no difference between ARM and FWD (P=0.999). A moderate effect size was found for HR comparing UR to ARM (d=0.643) and FWD (d=0.649).

Oxygen Consumption

VO_2 increased from 23.37 ± 3.53 for UR to 24.69 ± 3.67 for ARM and 25.11 ± 3.74 mL·min^{-1}·kg^{-1} for FWD. Increases were statistically significant for both ARM (*P* = 0.001) and FWD (*P* < 0.001) relative to UR, with no difference between ARM and FWD (P=0.628). A moderate effect size was found when comparing UR to FWD (d=0.478), while a small effect size was found when comparing UR to ARM (d=0.367).

Energy Expenditure

Energy expenditure increased from 9.126 ± 2.09 for UR to 9.674 ± 2.16 for ARM and 9.826 ± 2.07 $kcal \cdot min^{-1}$ for FWD. Increases were statistically significant for both ARM (P<0.001) and FWD (P<0.001) relative to UR, with no difference between ARM and FWD (P=0.912). A small effect size was evident for the UR condition when compared to either ARM (d=0.258) or FWD (d=0.336).

DISCUSSION

The findings in this study partially support the experimental hypothesis, as differences were evident in metabolic cost among different user-machine interactions on a CT at a constant machine workload. The greatest increase in metabolic cost was not the condition during which the subjects used their arms to contribute to the work output. Both using the arms (6.0%) and leaning forward while anchoring the upper body (7.7%) resulted in statistically significant increases in energy expenditure relative to working upright and unsupported, and they were not statistically different from each other. These differences are independent of any machine settings that would be used to quantify machine workload.

These findings have two main applications. First, caloric expenditure can be altered by as much as 7.7% by simple postural alterations while at the same machine workload. This information might be of value to individuals looking to increase energy expenditure without necessarily increasing the machine workload. Secondly, these data suggest that postural alterations could be a possible confounding factor for any experiment during which energy expenditure is an outcome during non-impact cardiovascular cross training. That is, simply controlling for machine workload alone likely is not sufficient for normalization across subjects.

Previous research has shown a 2.6% increase in VO_2 during elliptical exercise when using the handles compared to the absence of arm activity (12). The results of the present study demonstrate a greater increase in oxygen consumption by the introduction of the upper extremity on this CT when compared with similar conditions of elliptical trainers. This may be due to the fact that the exercise modality utilized during this experiment features mobile handles that move in the same direction as the footplates, which is opposite to the reciprocal pattern employed by many CTs. As a result, it is possible that the use of the arms on the CT in the present study contributed more to the work output. This may reflect the higher metabolic cost in this posture compared to that which was shown by incorporating one’s arms on the elliptical trainer. Future research should examine whether these differences elicit changes in RPE during exercise relative to conditions during which users do not employ the use of the mobile arms.

To the authors’ knowledge, no study has directly examined the differences in metabolic cost associated with postural alterations on the device used in the present study. However, a number of related studies have been performed for stationary cycling. One such study (14) found that flexing the trunk 20° resulted in a significant increase in gluteus maximus activity relative to conditions in which the trunk was in a neutral position or extended 20°. Another study (9) found that flexing the trunk to 70 degrees led to significant increases in gluteus maximus and vastus medialis activity relative to flexing the trunk to 50 degrees when cycling at the same speed and power output. Changes in trunk orientation have also been shown to affect the dynamics of many lower extremity muscles (2,14), which is very likely due to the changes in muscle lengths (14) and lower extremity joint torques (2,8).

When cycling at intensities greater than 60% of VO_2 max, it appears that increasing power output is driven by a marked increase in gluteus maximus activation relative to other lower extremity muscles and a significant decrease in efficiency (1). Although the decrease in efficiency is probably related to an increase in reliance on anaerobic energy systems, there appears to be some association between decreasing efficiency and gluteus maximus activity.

It appears that by leaning forward and anchoring the upper body the subjects in the present study may have switched emphasis to a more hip extensor dominant movement, which was subsequently manifested as an increase in metabolic demand. Past research (13) on an elliptical trainer has shown that gluteal muscle activation was not markedly different between exercising while grasping stationary handles, using the mobile handles, or while freehanded. This may be accounted for by the fact that the differences in upper body posture were minimal between the conditions on the elliptical trainer. In addition, these data may simply reflect the differences between elliptical trainers and the CT used in the present study. An investigation of the lower extremity joint torques on this exercise modality would elucidate the role of hip, knee, and ankle torques on metabolic cost.

Limitations

There are certain limitations related to the present experimental design. It is not directly clear from the present study if the differences in metabolic demand are also associated with concomitant increases in RPE. If so, as is possible considering the statistically significant increase in HR, it is not clear which would be the optimal exercise prescription to maximize energy expenditure during a workout with a pre-defined duration. In addition, these results are likely only applicable to this particular device; extending these findings to other forms of cardiovascular exercise or cross trainers should be done with caution. Our subject population included both males and females, which was our goal to include a wide cross-section of ages. As such, our results may not be directly applicable to specific sub-populations (e.g., healthy young athletes). Room temperature and humidity were not controlled for inter-subject, although these factors were accounted for in the respiratory measurement system's default software before each trial.

Other factors such as caffeine intake, sleep, hydration, and extra-experimental exercise were not explicitly controlled for. However, the confounding effects of these factors were somewhat mitigated by ensuring that each of the subjects' two trials was performed at the same time of day and within 7 days of each other. By limiting the total duration of exercise to approximately 12 min, we made an effort to minimize the effects of cardiovascular drift (10). In an extended effort to reduce these confounding effects, all subjects were recorded on two separate days, with each testing session imposing a different order of experimental conditions. Given that statistical analyses confirmed no main effect for testing day on any of the dependent variables, it is reasonable to conclude that the effects of cardiovascular drift were minimized.

CONCLUSIONS

Caloric expenditure is increased a small but significant amount depending on the user's interaction with a cross trainer, even when the machine's settings (speed, resistance, and incline) are held constant. This finding should be of value for individuals aiming to maximize caloric expenditure during exercise, without necessarily having to change any settings. Despite the limitations of any machine's estimate for EE, it is often used by many during exercise to aid in balancing caloric intake and output as a part of a weight loss regimen. The results of this study suggest that there are relatively simple ways within an exercise session to modulate caloric expenditure. If these changes are associated with differences in RPE, then a coach or trainer can apply this information in order to personalize a cardiovascular exercise prescription on the cross trainer that was used in the present study.

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